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US Army Redstone Test Center (TEDT-AC-FT-I)
Building 30133
Cairns Army Airfield
Fort Rucker, Alabama 36362-5276

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The development, modernization, and integration of electro-optical sensors into U.S. Army aviation weapon systems necessitate a conclusive strategy for evaluating system level performance. While most sensors are tested in a laboratory environment, consideration must be given to the possible degradation in performance after installation on an aircraft. The following test procedures, data reduction and performance analysis will be applicable to MRTD testing of electro-optical sensors installed on an aircraft inside or outside of a laboratory environment. These pocedures are needed to support current and future customers. RTC maintains equipment to perform numerous electro-optical sensor tests. The Athermal Collimator Test Set (ACTS) provides traditional static target projection to assist the test engineer in characterizing electro-optical sensors.

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U.S. ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure (TOP) 06-3-014 23 March 2011
DTIC AD No.

# METHODOLOGY PLAN FOR MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE (MRTD) TESTING OF AIRCRAFT INSTALLED SENSORS

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1. SCOPE.

This document is intended for official use by the U.S. Army Developmentat Test Command and its subordanite test centers. Information and many of the procedures in this document are based on the International Test Operations Procedure (ITOP) 06-3-040[1]. Certain methodologies may need to be changed to accommodate testing a sensor already installed on an aircraft outside of a laboratory environment. Deviations from the ITOP may be acceptable but should be consistent with other accepted government and contractor procedures. All personnel who are engaged in the preparation, testing, reporting, or observation of contractor testing should become intimately familiar with the contents of this document and ensure that test operations are conducted in compliance with the defined procedures. The references contained in Appendix J are for informational purposes only and to aid in the understanding of the test methods to be applied. Description of specific equipment within this TOP does not imply an endorsement of that manufacturer's equipment. It is included in order to offer realistic details of how the procedure is performed at the Redstone Test Center (RTC).

1.1 Introduction.

The development, modernization, and integration of electro-optical sensors into U.S. Army aviation weapon systems necessitate a conclusive strategy for evaluating system level performance. While most sensors are tested in a laboratory environment, consideration must be given to the possible degradation in performance after installation on an aircraft. The following test procedures, data reduction and performance analysis will be applicable to MRTD testing of electro-optical sensors installed on an aircraft inside or outside of a laboratory environment. These pocedures are needed to support current and future customers. RTC maintains equipment to perform numerous electro-optical sensor tests. The Athermal Collimator Test Set (ACTS) provides traditional static target projection to assist the test engineer in characterizing electro-optical sensors.

1.2 Purpose.

The purpose of this document is to provide the test engineer and test director with a set of test operational procedures to measure the thermal resolution of thermal imaging sensors installed on aircraft as a function of spatial frequency.

1.3 Objectives.

a. Establish a standardized and comprehensive set of methodologies for Minimum Resolvable Temperature Difference (MRTD) testing of sensors installed on aircraft.

b. Provide an instructional resource for the operation and maintenance of RTC electro-optical test equipment.

c. Define methods for presenting and analyzing MRTD data within test plans and reports.

## 1.4 Policy.

This document provides supplemental test information to amplify or clarify MRTD procedures defined in the ITOP (06-3-040). For convience of the test director, much of the information contained in the ITOP has been copied directly to this document. However, if deviations from a provision of the ITOP are required due to constraints such as available facilities, national regulations or instrumental accuracies, the variation will be clearly identified and the rationale for the deviation will be provided.

## 1.5 Limitations and Assumptions.

The procedures in this document are intended to cover both scanning and staring military thermal imagers operating in the long-wave infrared (8-14μm waveband) and mid-wave infrared (3-5μm waveband) spectral regions. Any special circumstances concerning attributes of scanning versus staring arrays will be defined. It is assumed the measurement of the FLIR targeting and pilotage sights will occur in a laboratory or hangar environment. This document assumes that the operator has a working knowledge of the principles of optics and thermal imaging as well as testing in a laboratory or hangar environment. It is further assumed that the test operator is familiar with the characteristics of the test items. The test procedures included in this document should be applied to the performance parameters specified for the test items. Not all procedures will be required for every test item. Collimator efficiencies are usually given or measured as radiometric quantities but are typically implemented as a multiplying factor of the source temperature. This discrepancy is a common source of error. The field test procedures can be used when the thermal imaging sensor/subsystem cannot be separated from the host vehicle; however, the accuracy obtainable in field-testing may not reach that obtainable in the laboratory. It is essential that appropriate guidelines and standard laboratory operating procedures for safety are followed.

# 2. FACILITIES AND INSTRUMENTATION.

Facilities and instrumentation will vary among different test sites and should be covered within that test site's specific test procedures. MRTD testing requires the use of an optical collimator capable of covering the span of spatial frequencies specified for the test item. Appendix B describes the typical collimator system design and how it is used during (EO/IR) testing. An explanation of RTC's facilities and instrumentation is described in Appendix C, and the RTC collimator operations and maintenance procedures are defined in Appendices D and E.

# 3. REQUIRED TEST CONDITIONS.

This section is provided for the test director as general guidance regarding items that need to be addressed before testing begins. Although this section provides a general overview of the required test conditions, the reader will be guided to more specific information within this document as required. A checklist is provided to simplify and expedite test developments.

3.1 Pre-test Planning.

a. Test Plan.

(1) Prior to initiating the test program, a test plan must be prepared. The test plan shall:

(a) Follow the guidelines set forth in RTC Memorandum 70-12[2] for planning, executing, reporting and completing test activities.

(b) Describe each test to be performed in sufficient detail to be understood by test personnel and approving authorities.

(c) Describe the measurements to be made, the test criteria, and the data reduction and analysis techniques to be used.

(d) Describe the test set-up for each test and the instrumentation to be used.

(e) Identify the required environmental conditions, profiles and limits for each test, as well as the number and location of environmental condition sensors.

(1) The pre-test planning shall also include:

(a) Adequate safety procedures for test personnel.

(b) A briefing to test personnel on all aspects of the test program, including the purpose of each test, the measurement requirements, and the preparation and operation of all test instrumentation.

(c) Sufficient copies of all test item and instrumentation operating instructions and safety procedures.

3.2 Preparation.

a. Facilities.

Preparation of test facilities shall include:

(1) Adequate lead time to ensure the facility will be available for the duration of the test program.

(2) Assurance that facility environmental equipment is in proper operating condition.

(3) In terms of laboratory requirements, conformance to optical darkroom standards is essential, as is good floor stability, although extreme levels of vibration damping

are not normally required. However, care must be taken to ensure that the levels of vibration, air turbulence, temperature variation, etc., do not interfere with resolution measurements (e.g., MRTD, MDTD, and MTF). The working area should provide easy access to all parts of the system.

(4) If the laboratory area is normally clean and dry, clean room conditions (temperature, dust, and humidity control) are not normally required. Unless otherwise specified, an ambient temperature of 20°C to 25°C and a relative humidity of about 50% are generally satisfactory. For some measurements, control of environmental conditions may be required to meet test plan requirements.

b. Instrumentation.

Prior to initiating the test program:

(1) Ensure that all test instrumentation is in proper operating condition.

(2) Ensure that test personnel are adequately trained to operate the test instrumentation.

(3) Ensure all test instrumentation is available for the test program.

(4) Ensure that the calibration of all test instrumentation is current and will extend through the test period.

(5) Ensure that the accuracy of all test instrumentation will meet the test requirements.

(6) If time permits, a demonstration or dry-run of the test procedures may be prudent.

c. The use of automated test instrumentation should be considered during the test planning process.

d. Specific test instrumentation requirements are listed in the individual test procedures (see appendix D).

e. For off-site test activities, identify commercial carrier capable of shipping test equipment. Cost for this must be considered early and arrangements become difficult if test activities are not well defined. Also, it is imperative to coordinate access to spare equipment in case it is required. Consider taking critical spare equipment with the test instrumentation, but arrange to have personnel available during test hours to expedite shipping spare equipment at a later date.

3.3 Test Item.

a. Prior to initiating the test program:

(1) Inspect the test item for damage, completeness, deterioration, or manufacturing defects and record any deficiencies.

(2) Ensure that the test item is in proper operating condition.

(3) Ensure that operating manuals for the test item are available.

b. Provide a description of the test item(s). If available, the description should include, but not be limited to, the following:

(1) A description of the intended use of the test item.

(2) A description of each operating mode of the test item.

(3) Photographs of the test item mounted in the host vehicle and, if possible, outside the host vehicle.

(4) The test item specifications for each attribute to be measured.

(5) The physical characteristics (i.e., weight and dimensions) of the test item.

(6) A schematic diagram of the test item, its components, and its interface to other sub-systems in the host vehicle.

(7) A description of all control features of the test item.

c. Test personnel shall be adequately trained to operate the test item and be familiar with all operating modes and controls.

## 4. TEST PROCEDURES.

General: All testing procedures for MRTD will be done in accordance with Chapter 4.1 of the ITOP. The plan for supporting an MRTD test calls for a test director, test engineer, test technician and three (3) test subjects. The following diagrams (Figure 1, Figure 2, Figure 3, and Figure 4) provide a process flowchart for each of the test support personnel and identify their primary responsibilities. The header identifies the main sections of this document that will be of most importance to these personnel. For test procedures and test conditions specific to RTC, see Appendices F and G.

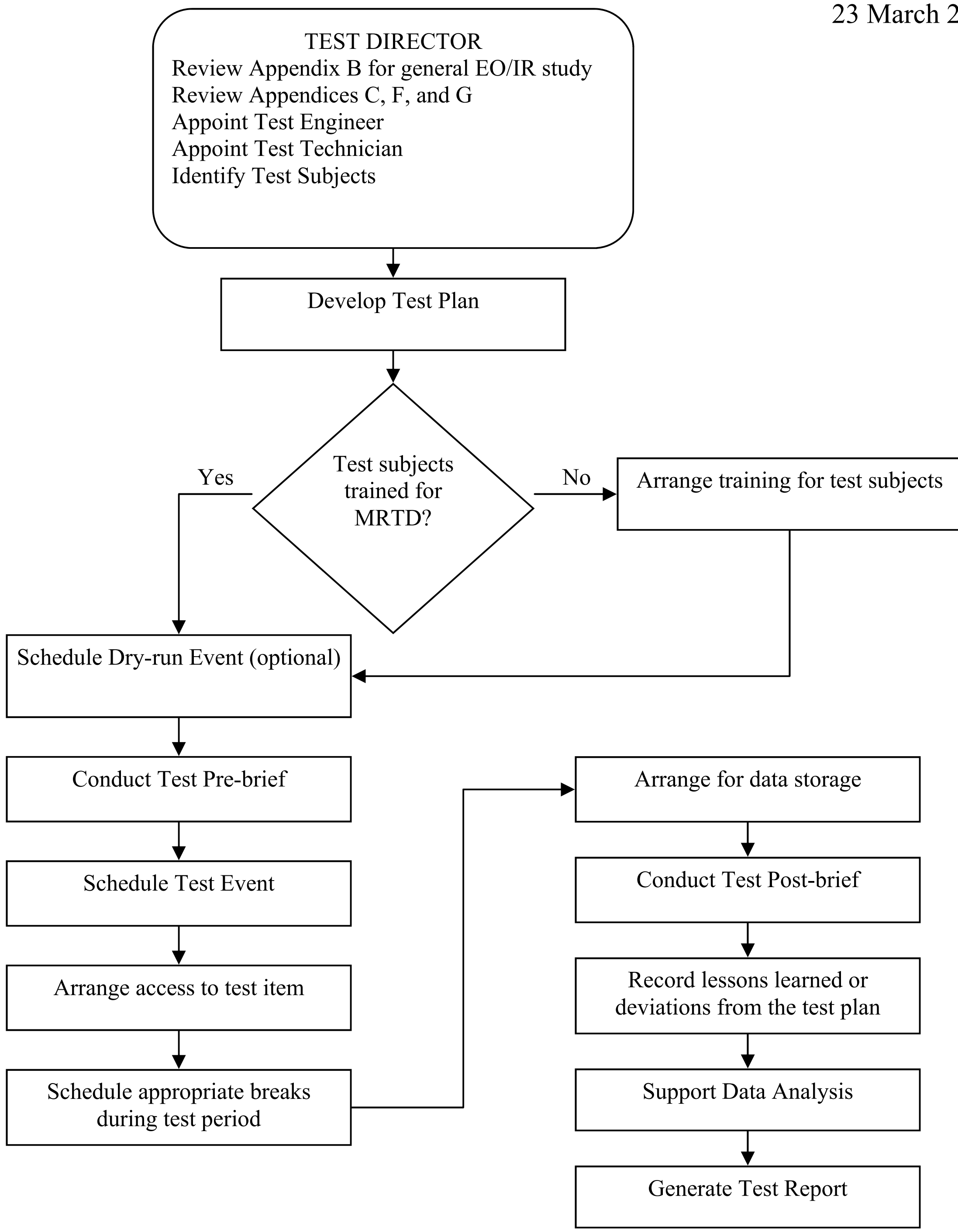


Figure 1. Test Director Process.

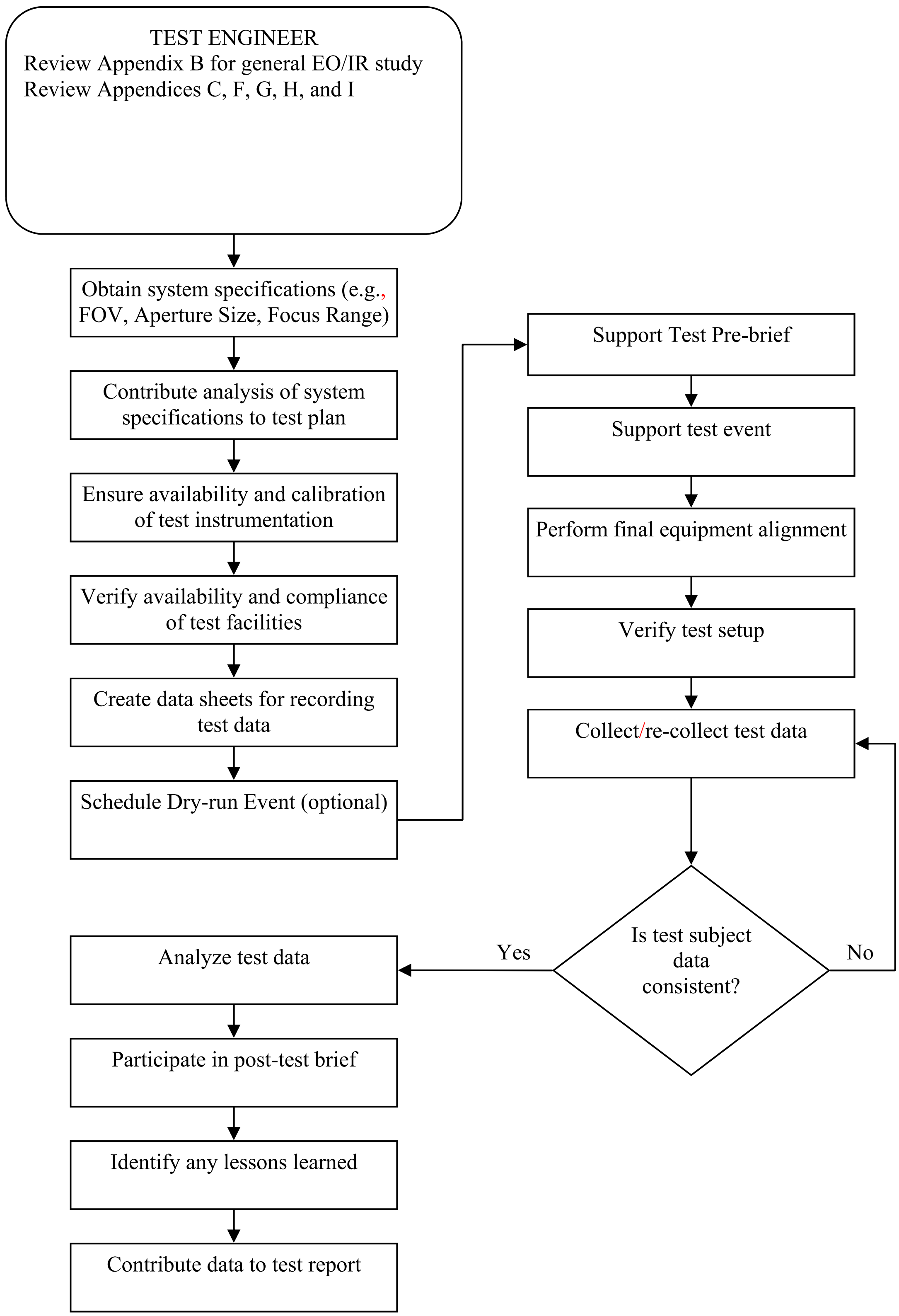


Figure 2. Test Engineer Process.

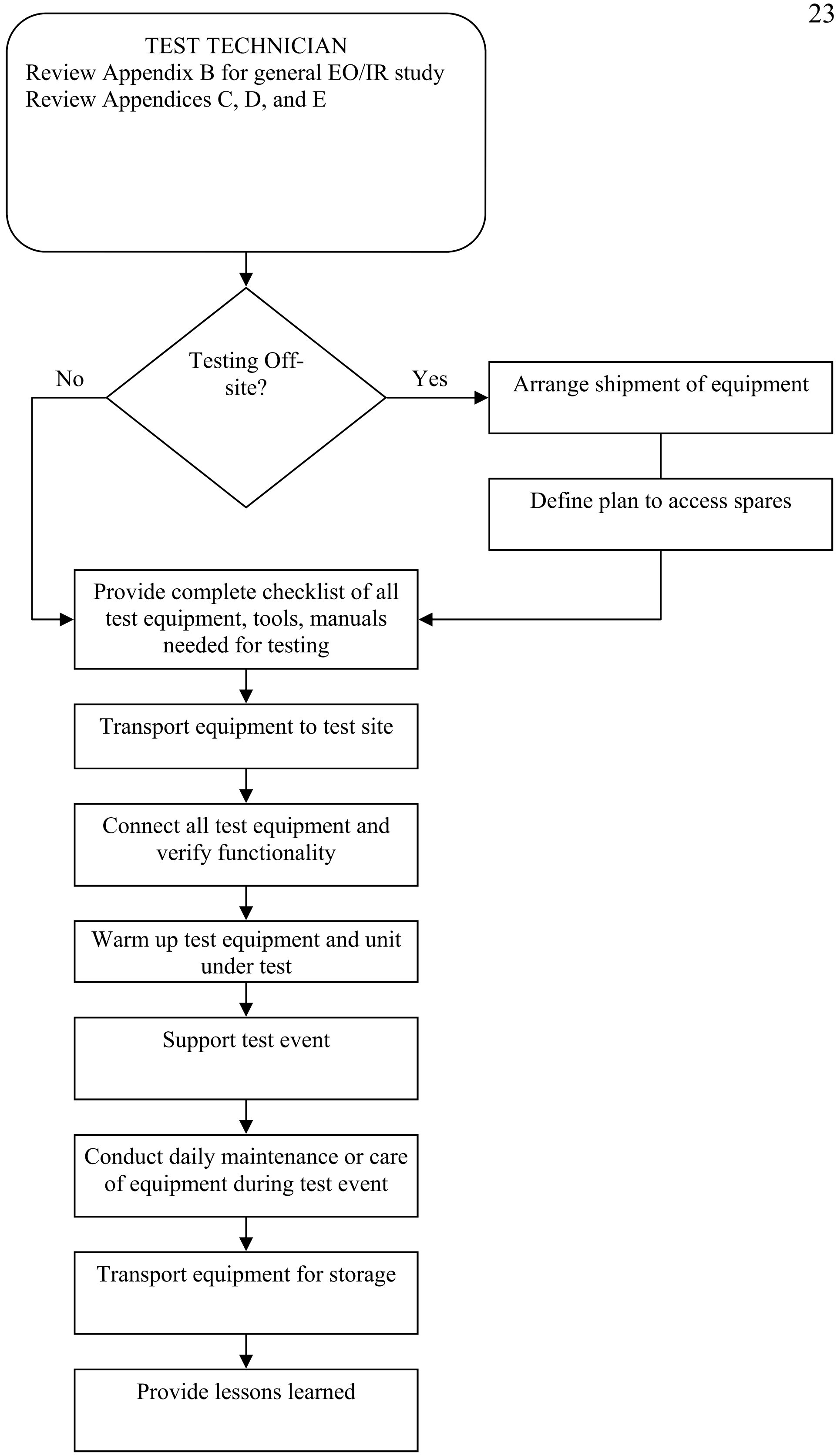


Figure 3. Test Technician Process.

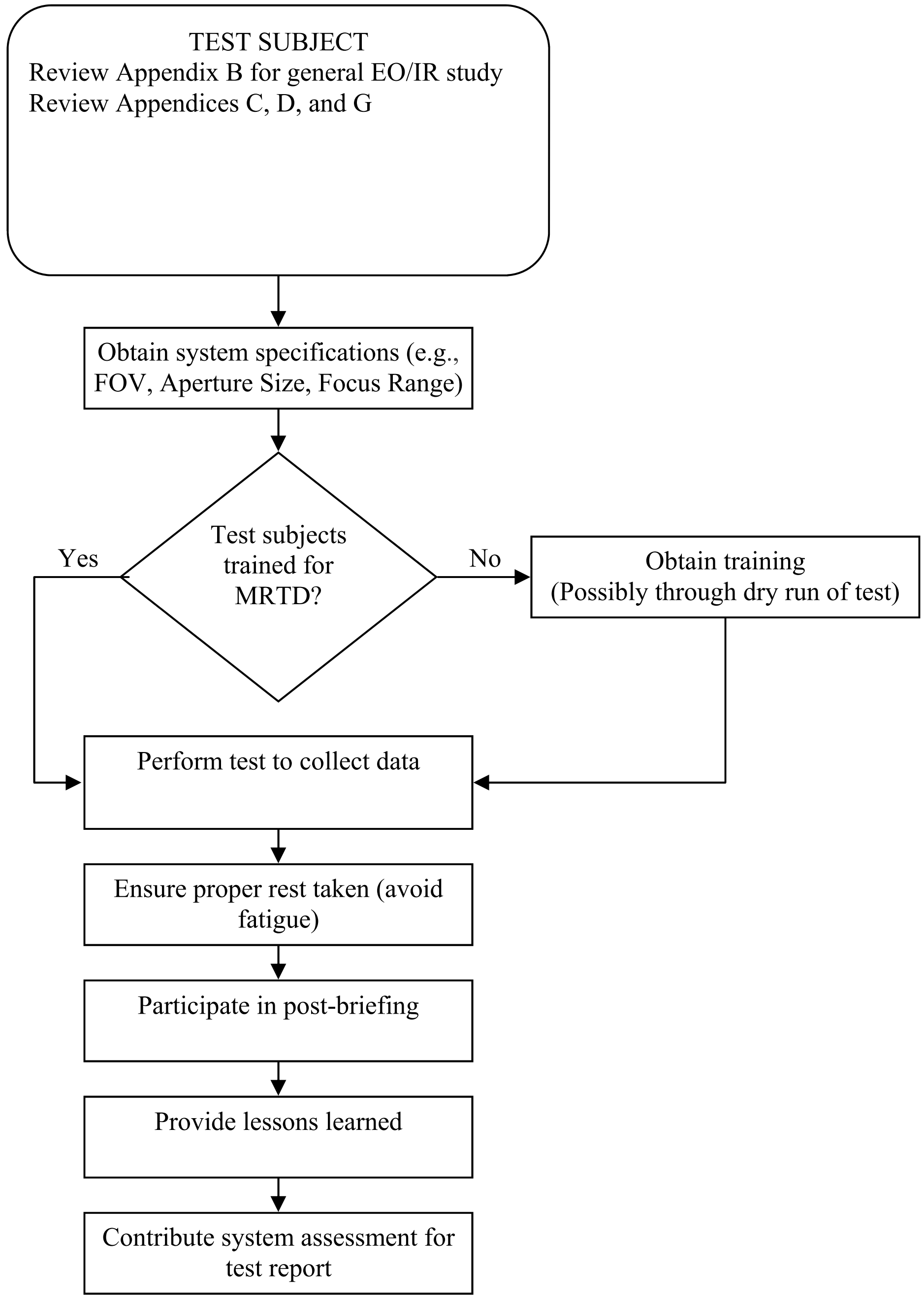


Figure 4. Test Subject Process.

5. DATA REQUIRED.

a. General. Where applicable, the following general data are required for each test performed:

(1) Laboratory and/or field environmental conditions.

(2) Participating observers' names, identifiers, and their visual acuities if necessary.

(3) Test item manufacturer, type, and serial number.

(4) Test item settings.

(5) Test item operating waveband, detector angular subtense?, entrance pupil size and location for each field-of-view.

(6) Measurement equipment manufacturer, model number, serial number, and calibration date.

(7) Drawing of test set-up.

(8) Time and date of tests.

(9) Measurement uncertainty of the test data/results.

b. Specifics. The data requirements specific to individual tests are listed in the appropriate test procedure/paragraph, e.g., calibration (see appendix D).

6. PRESENTATION OF DATA.

Presentation of data and data analysis shall be done in accordance with Chapters 4.1 and 5.2 of the ITOP. A more detailed method for analysis and presentation of data at ATTC is shown in Appendices H and I.

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# APPENDIX A. DEFINITIONS.

The following is a list of terms contained herein or commonly associated with the operation, maintenance and analysis of thermal imager testing.

**Accuracy (Measurement Accuracy)** – The accuracy of a measurement refers to how close a measured value is to the true value or an accepted value. The difference between the measured value and the true or accepted value is the error. This error is a combination of all systematic and random sources of error in the measurement system. The accuracy of a measurement can never be better than ± half the resolution of the measuring equipment but may be worse than this.

**Aliasing** – "Aliasing" is the result of a sampling frequency that is too low to preserve the spatial frequencies of the scene being sampled. When the frequency content in a scene is greater than half the sampling frequency, it appears in the sampled scene at a lower (aliased) frequency.

**Ambient Temperature** – The ambient temperature is the prevailing temperature in the immediate vicinity of an object or within defined surroundings.

**Angular Subtense** – The geometrical angle subtended by the edges of an object or image being viewed, or projected; usually expressed in milliradians.

**Apparent Temperature Difference (Thermal Contrast)** – The apparent temperature difference is the apparent blackbody differential temperature between an unvignetted target and background, within the spectral waveband of the test items. The distinction between "apparent" and "actual" temperature difference is used to take into account emissivity, atmospheric, environment, and/or projection optic losses.

**Atmospheric Transmission (Radiometric, Spectral)** – The atmospheric radiometric transmission, $\overline{\mathrm{T}}_{\mathrm{Atm}}$, over a specified range is defined by the equation:

$$\overline{\mathrm{T}}_{\mathrm{Atm}} = \frac{\int_{\lambda 1}^{\lambda 2} \mathrm{T}_{\mathrm{Atm,R}}(\lambda) \mathrm{F}_{\mathrm{s}}(\lambda) d\lambda}{\int_{\lambda 1}^{\lambda 2} \mathrm{F}_{\mathrm{s}}(\lambda) d\lambda}$$

Where $\mathrm{T}_{\mathrm{Atm,R}}(\lambda)$, is the atmospheric spectral transmission, given by the ratio of the power on a detector from a monochromatic, collimated source at range, R, to its value at zero range. $\mathrm{F}_{\mathrm{s}}(\lambda)$ is the spectral power of a polychromatic source, and $\lambda_1$ and $\lambda_2$ define the waveband of interest.

**Background Temperature** – For the purposes of this TOP, the background temperature is the temperature of the target plate, used as part of a thermal target for the measurement of MRTD or MDTD. The background temperature will not necessarily be the same as laboratory ambient temperature, (? the comma) owing to the effects of thermal radiation from the blackbody source.

APPENDIX A. DEFINITIONS.

**Biocular** – The term "biocular" designates any optical instrument in which both eyes may be used to view an image through a single element to facilitate viewing.

**Collimator** – A collimator is an optical instrument consisting of a well-corrected objective lens or an off-axis parabolic reflector (typically a peak to valley wavefront error of less than $\lambda/8$). For many test applications, a collimator is used to make an object placed in its focal plane appear to be at infinity.

**Collimator Radiometric Efficiency** – The collimator radiometric efficiency, $\overline{R}$, is defined by the equation:

$$\overline{R} = \frac{\int_{\lambda 1}^{\lambda 2} R(\lambda) F_s(\lambda) d\lambda}{\int_{\lambda 1}^{\lambda 2} F_s(\lambda) d\lambda}$$

where $R(\lambda)$ is the collimator spectral transmission or reflection, $F_s(\lambda)$ is the spectral power of a polychromatic source and $\lambda_1$ and $\lambda_2$ define the waveband of interest.

**Collimator Working Distance** – The collimator working distance is the maximum distance at which the beam from the collimator fills the entrance pupil of the test item for all points in the test item's field-of view, as shown in Figure A-1.

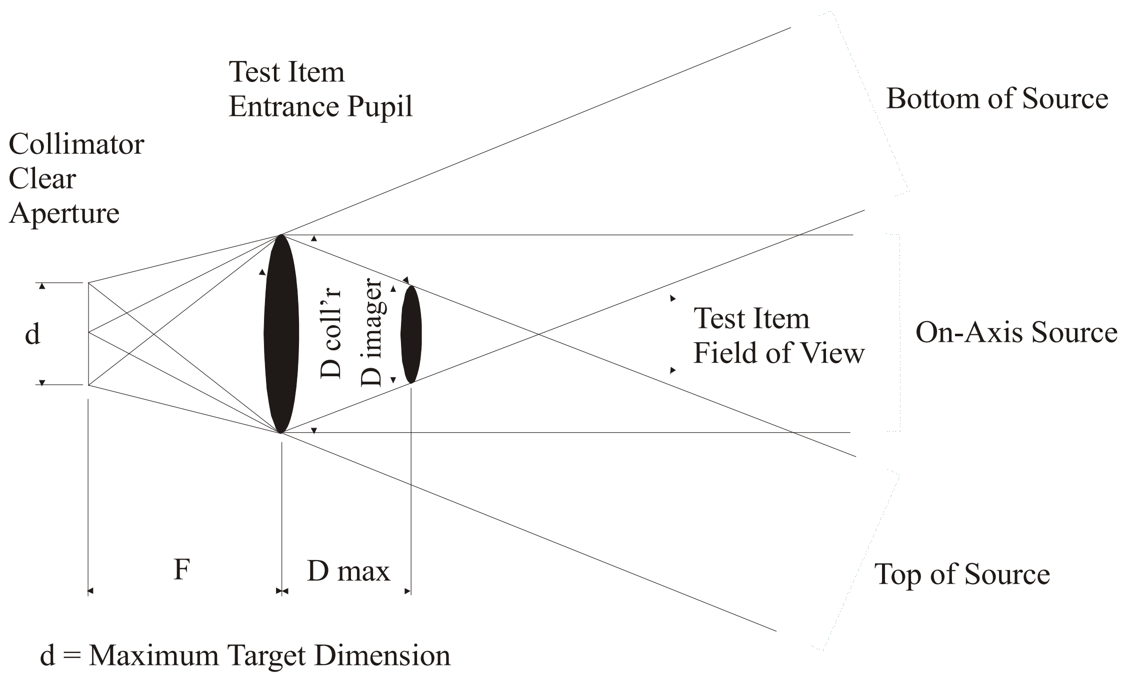


**Figure A-1. Collimator Working Distance**

The collimator working distance in metres, $D_{max}$, is given by:

APPENDIX A. DEFINITIONS.

$$D_{max} = \frac{(D_{coll'r} - D_{imager}) * F}{d}$$

where $D_{coll'r}$ is the aperture diameter of the collimator (mm), $D_{imager}$ is the aperture diameter of the test item (mm), F is the focal length of the collimator (m) and d is the maximum dimension of the collimator target (mm).

**Cut-off Frequency** – The spatial frequency at which the modulation transfer function falls to zero, or, for practical use, below some specified amount such as 3%. The cut-off frequency ($f_{co}$) for a diffraction limited optical system is given by:

$$f_{co} = \frac{1}{\lambda\,(mm) * f_{no}} (cy/mm) \quad \text{in image space, or}$$

$$f_{co} = \frac{D(m)}{\lambda\,(mm)} (cy/mr) \quad \text{in object space}$$

where $\lambda$ is the measurement wavelength, $f_{no}$ is the f-number, and D is the entrance pupil diameter of the test item.

**Derotation** – In a panoramic optical system the image rotates about the optical axis as the system objective is rotated. The image rotation is compensated for, i.e., the image is de-rotated, by additional optical components in the system. The term derotation is a measure of the system's ability to correct for image rotation.

**Detector Angular Subtense** – The paraxial solid angle subtended by a single detector active area. For a rectangular detector active area of width, w, and height, h, the detector angular subtense through an imager of effective focal length, f is given by:

$$DAS = \frac{w}{f} * \frac{h}{f} (rad^2)$$

Typically, the width and height of the detector element are defined to be in the horizontal and vertical planes of the imager's coordinate system, respectively. For this case, the horizontal and vertical one-dimensional detector angular subtenses are given by:

$$DAS_h = \frac{w}{f} (rad)$$

$$DAS_v = \frac{h}{f} (rad).$$

**Diffraction Limited System** – The term diffraction limited implies that the performance of an optical system is limited by the physical effects of diffraction rather than geometrical imperfections in either the design or fabrication.

APPENDIX A. DEFINITIONS.

**Distortion** – Distortion is an image defect (aberration) in which the magnification is not constant over the field-of-view. For radial distortions, the following polynomial can be used to describe the variation of magnification with field angle (ω):

$$M(\omega) = M_0 + A\omega + B\omega^2 + C\omega^3 + D\omega^4,$$

where $M_0$ is the paraxial magnification. Distortion indicates the percentage difference in magnification of an off-axis object compared to a paraxial object and can be expressed as:

$$D(\omega) = \frac{M(\omega) - M_0}{M_0} \times 100\%$$

For example, a negative radial distortion deforms a square grid object into a barrel shape (barrel distortion) and a positive radial distortion deforms a square grid object into a pillow shape (pincushion distortion). Figure A-2 shows the effect of different types of distortion on a square grid object.

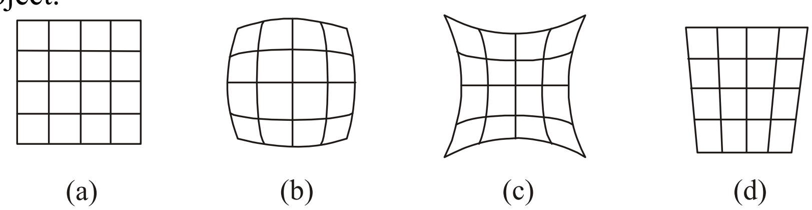

**Figure A-2 Examples of Distortion**

**DRI** – The acronym for Detection, Recognition, and Identification, where:

> Detection is the determination of the presence of an object of interest. For example, the object is believed to be of military interest and warrants further investigation.
>
> Recognition (classical) is the determination of the specific class to which a detected object belongs. For example, a detected object of military interest can be classified as a tank, as opposed to an armored personnel carrier, which are both within the general class of tracked vehicles.
>
> Identification is the determination of the specific type within the class to which a recognized object belongs. For example, the object of military interest is a T-72 as opposed to other types of tanks

**Drift** – Slow, large amplitude movement of the image that can be followed by the observer's eye.

APPENDIX A. DEFINITIONS.

**Effective Focal Length** – The effective focal length is the distance from the principal point to the focal point.

**Effective Ranges (50% Probability)** – The effective ranges are the distances at which 50 percent of the detection, recognition and identification (DRI) observations can be successfully conducted and are designated "$R_{d50}$," "$R_{r50}$," and "$R_{i50}$," respectively.
**Emissivity** – The ratio of an object's spectral radiance to that emitted by a blackbody radiator at the same temperature and at the same wavelength. Although emissivity is a function of wavelength, it is commonly stated as a broad-band average.

**Entrance Aperture** – The entrance aperture is the first physical aperture of the optical system that limits incoming rays parallel to the optical axis, typically the mechanical housing of the objective.

**Entrance Pupil** – The entrance pupil is the image of the aperture stop formed by the optical elements between the aperture stop and the object.

**Entrance Window** – The entrance window is the first optical element of the optical system intersected by a ray originating from a distant object. In some systems, the entrance window is a protective assembly without optical power.

**F-Number (F#, F or $F_{NO}$)** – The ratio of the effective focal length of an optical system to the diameter of its entrance pupil. The f-number is also known as the aperture ratio.

**Field-of-View** – The limits of the field or area displayed by, or viewed through, an optical/electro-optical system. The field-of-view is usually expressed in angular terms.

**Figure of Merit** – Any parameter which is used to define the performance of a system against a standard metric. A figure of merit is typically defined to highlight (i.e., weight) or combine specific performance parameters into a single evaluation parameter. Figures of merit can be highly subjective and/or biased by the manner in which they are defined and must be used with caution.

**Flicker** – Flicker is intensity variations of the displayed image as a function of time. If the flicker frequency is above the frequency that is detectable by the human eye, no image degradation will be perceived. A low frequency flicker (20 Hz or below) can have a disturbing effect on the observer and thereby limit the effectiveness of the imaging system.

**Focal Point** – The point on the optical axis to which an incident bundle of parallel rays will converge.

APPENDIX A. DEFINITIONS.

**Fourier Transform** – The Fourier transform of a function f(x) is defined as:

$$F(s) = FT\{f(x)\} \equiv \int f(x) \cdot e^{-i2\pi xs} dx \ .$$

**Goniometer** – A goniometer is an opto-mechanical device used to measure angles. It typically comprises a low magnification telescope with an extended reticle for alignment, a remote entrance pupil about which it can rotate and a means of measuring its angle of rotation.

**Image Space (IS)** – The region in which the image, formed by radiation which has passed through an optical system, exists.

**Infrared Scene Projection (IRSP)** – IRSP is the capability to project collimated, in-band infrared scenes into the entrance aperture of a thermal imager under test. Note that IRSP is also used for Infrared Scene Projector, indicating a system of hardware and software configured to project infrared scenes.

**Jitter** – High frequency (i.e., usually beyond the frequency detectable by the human eye), small amplitude, lateral displacements of the image as represented in Figure A-3. If several frames are averaged (time domain averaging) to improve the signal-to-noise ratio, this can cause broadening of the averaged Line Spread Function (LSF). In this case it may be better to average a number of Modulation Transfer Functions (MTFs) (frequency domain averaging), by taking the Root Mean Square (RMS) and using the inverse Fourier transform to recover the LSF.

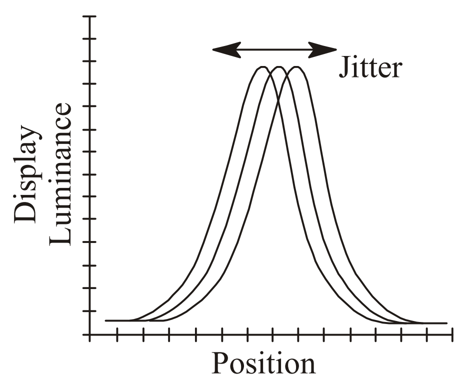


**Figure A-3. Jitter (High Frequency Lateral Movement of the LSF)**

APPENDIX A. DEFINITIONS.

**Linearity** – A function which describes the difference between the position of a point in the image space (measured as a fraction of image space half field-of-view) and its corresponding point in the object space (measured as a fraction of object space half field-of-view). It is related to distortion, but by definition is zero at the edge of the field-of-view. Magnification (M) as a function of off-axis angle (ω) can be described by the polynomial:

$$(\omega) = M_0 + A\omega + B\omega^2 + C\omega^3 + D\omega^4$$

where $M_0$ is the paraxial magnification. Linearity as a function of object and image space field angles ω and ω′ is given by:

$$L = 1 - \frac{\omega'}{\omega\overline{M}}$$

where $\overline{M}$ is the average magnification over the field-of-view ($\overline{M} = (d/2f)/\tan(FOV/2)$) where FOV/2 is the angle from the optical axis of the test item to the edge of the field-of-view in object space, d is the diameter (or side) of the field-of-view in image space and f is the effective focal length of the optics.

**Line Spread Function (LSF)** – The irradiance distribution function describing the image of a line, in the axis perpendicular to the line.

**Magnification (Angular)** – Given an object on the optical axis which subtends an angle ω in object space and ω′ in image space, the angular magnification of the object is:

$$M(\omega) = \frac{\tan(\omega')}{\tan(\omega)}$$

where ω and ω′ are expressed in radians. For small angles, this expression may be approximated to ω′/ω.

**Minimum Detectable Temperature Difference (MDTD)** – The MDTD is a subjective measurement of a thermal imager's ability to discriminate between a target and its immediate surroundings. It represents the minimum apparent temperature difference between a square or circular target and the background at which the target can just be detected, at a specified apparent background temperature. MDTD is usually performed over a range of target sizes.

**Minimum Resolvable Temperature Difference (MRTD)** – The MRTD is a subjective measurement of the thermal resolution of a thermal imaging device, as a function of spatial frequency. It represents the minimum apparent temperature difference between target and background when a standard 4-bar target with a 7:1 aspect ratio of known fundamental spatial frequency is just barely resolvable, at a specified apparent background temperature. MRTD is usually performed over a range of vertical and horizontal spatial frequencies.

APPENDIX A. DEFINITIONS.

**Modulation** – In general, the system induced change in the properties of an input wave train as seen in the output wave train, (e.g., amplitude, frequency and phase). In optics, modulation is used as a synonym for contrast, especially when applied to a bar target imaged by an optical system.

**Modulation Transfer Factor** – The ratio of the image contrast to the object contrast for a sinusoidal object at a given spatial frequency.

**Modulation Transfer Function (MTF)** – The MTF is a measure of an optical system's ability to transfer the contrast (i.e. modulation) of an object to its image. This function, usually represented graphically, shows the normalized modulation transfer factor of image to object contrast of a sinusoidal object plotted as a function of spatial frequency.

**Noise Equivalent Temperature Difference (NETD)** – The NETD is the effective blackbody target-to-background temperature difference in a standard (low spatial frequency) test pattern (e.g., a large single bar target) which produces a peak signal to rms-noise ratio of one.

**Nyquist Criterion** – In image acquisition, the sampling frequency must be at least twice the highest frequency component in the image data being sampled.

**Nyquist Frequency** – The highest spatial frequency which a sampled system can accurately reproduce, in accordance with the Nyquist criterion. This is given by: $F_N = 1/(2\alpha)$, where $\alpha$ is the detector angular subtense (mr) and $F_N$ is the Nyquist Frequency (cy/mr).

**Object Space (OS)** – The region from which radiation enters the entrance pupil of an optical system and in which the object resides.

**Objective** – The objective of an optical system is the element, or combination of elements, that receives light from the object and forms the first or primary image.

**Optical Axis** – The line passing through both centers of curvature of the optical surfaces of a lens; the optical centerline for all the centers of a lens system.

**Optical System** – An optical system is a group of refractive and/or reflective components designed to perform a specific optical function.

APPENDIX A. DEFINITIONS.

**Optical Transfer Function (OTF)** – The OTF is a functional relationship describing an optical imaging system's ability to transmit the spatial frequency components of an object to its image. The OTF is a complex function comprising modulation (real) and phase (imaginary) information. The respective parts are known as MTF and PTF, and are defined by:

$$OTF(\xi) = MTF(\xi)e^{-iPTF(\xi)}$$

where $\xi$ is the spatial frequency in cycles/milliradian (cy/mr) or an equivalent measure.

**Over-sampled Imager** – A thermal imaging system is over-sampled when there are more than two samples per cycle at the highest spatial frequency transmitted by the system. Scanned imaging systems may be over-sampled in the line-scan direction.

**Panoramic Telescope** – A panoramic telescope is constructed such that the image remains erect and the eyepiece remains fixed as the line of sight is pointed in any horizontal direction.

**Parallax** – Parallax is the optical phenomenon that causes the apparent change in relative position between two objects when the eyepoint is displaced laterally. Parallax is observed in a telescope when the reticle is not located in the image plane and the image is observed along a line of sight that is not the optical axis of the system.

**Paraxial Ray** – A paraxial ray lies close to and almost parallel to the optical axis and obeys first-order, also called Gaussian, optics such that the ray's angle with the optical axis, $\mu$ (in radians), can be used in place of $\sin(\mu)$ or $\tan(\mu)$, in accordance with the small angle approximation.

**Pedestal** – A pedestal refers to the background signal level above zero reference.

**Phase Transfer Function (PTF)** – The functional relationship describing the relative phase shifts of the spatial frequency components of an image relative to its object. A phase shift of 180 degrees corresponds to a contrast reversal.

**Principle or Chief Ray** – A principal or chief ray is the ray from an off-axis object point that passes through the center of the aperture stop. The principal ray enters the optical system passing through the center of the entrance pupil and exits the system passing through the center of the exit pupil. It is the effective axis of an oblique beam.

**Principle Plane** – The intersection of the projections of the incoming and exiting paraxial rays.

**Principle Point** – The intersection of the principal plane with the optical axis.

APPENDIX A. DEFINITIONS.

**Properly-Sampled Imager** – A sampled thermal imaging system can be described as properly-sampled when its imagery is adequate to perform the application for which it has been designed. For the purposes of this TOP, where the term is used in the MRTD measurement procedure, the effects of aliasing on the appearance of the bar targets shall be sufficiently small that the measured MRTD at the spatial frequencies of interest is not significantly worse than an analog imager with the same optics and electronics MTFs.

**Radiometric Efficiency** – The radiometric efficiency, $\eta$, is defined by the equation:

$$\eta = \frac{\int_{\lambda 1}^{\lambda 2} R(\lambda) T_{Atm,R}(\lambda) F_s(\lambda) d\lambda}{\int_{\lambda 1}^{\lambda 2} F_s(\lambda) d\lambda} \approx \overline{R} \times \overline{T}_{Atm}$$

where $R(\lambda)$ is the collimator spectral transmission or reflection, $T_{Atm,R}(\lambda)$ is the atmospheric spectral transmission, $F_s(\lambda)$ is the spectral power of a polychromatic source and $\lambda_1$ and $\lambda_2$ define the waveband of interest. It is usually approximated by the product of the atmospheric radiometric transmission, $\overline{T}_{Atm}$, and the collimator radiometric efficiency, $\overline{R}$.

**Rayleigh Resolution Criterion** – For a circular, diffraction-limited (i.e. aberration free) lens with effective focal length, f, and aperture, D, as shown in Figure A-4, the images of two points are just resolved when they are separated such that the center of the Airy diffraction pattern of one point falls on the first minimum of the Airy diffraction pattern of the other.

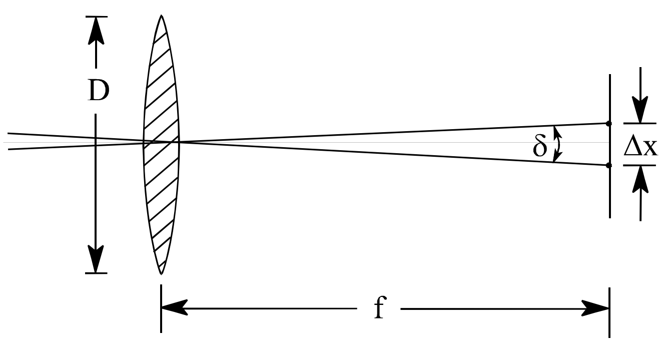


**Figure A-4. Resolving Points**

APPENDIX A. DEFINITIONS.

This resolution condition exists when the angular separation of the images of two object points is:

$$\delta[\mu r] = \frac{1.22\lambda[nm]}{D[mm]} = \frac{\Delta x\ [\mu m]}{f\ [m]}$$

The corresponding spatial frequency is:

$$\omega_{co}\left[\frac{cy}{mr}\right] = \frac{1000.0D[mm]}{1.22\lambda[nm]} \approx \frac{819.7D[mm]}{\lambda[nm]}$$

and in the image plane is:

$$\omega_{co}\left[\frac{lp}{mm}\right] = \frac{1000000}{1.22\ \ [nm]\dfrac{f\,[mm]}{D[mm]}} \approx \frac{819700}{[nm]f_{no}}$$

where $\lambda$ is the measurement wavelength and $f_{no}$ is the f-number.

**Reference Plane** – The plane, generally perpendicular to the optical axis of the system, to which all spatial frequencies and position parameters are referred. The reference plane may be at infinity in object space and the spatial frequency expressed in cy/mr.

**Relaxed View Display** – A display that can be viewed from the operator's normal seated posture. Examples are a CRT monitor, flat panel display and a biocular display.

**Resolution (Measurement Resolution)** – The resolution of a measuring instrument is the smallest positional or display increment that can be discerned by an observer. For a digital scale this will be one digit in the least significant position. In some cases, the ability to resolve can be enhanced by the use of aids that increase the measurement sensitivity.

**Reticle** – An optical element located at, or projected into, an image plane of an optical instrument that consists of a pattern (e.g., crosshair, linear, or angular graduations) to assist the observer when pointing the instrument or measuring target characteristics.

**Signal Transfer Function (SITF) or System Intensity Transfer Function (SITF)** – The SiTF is the curve or the family of curves that describe the output luminance or output system voltage of a device as a function of the input blackbody target-to-background temperature difference in a standard test pattern.

APPENDIX A. DEFINITIONS.

**SINC Function** – The mathematical function, denoted sinc(x), is defined as:

$$\mathrm{sinc}(x) = \frac{\sin(\pi x)}{\pi x}.$$

**Spatial Frequency (Fundamental)** – The reciprocal of the period of a repetitive object such as a sine wave or series of equispaced lines or bars. Figure A-5 shows a standard four-bar target with a bar width equal to b, a bar spacing equal to b, and a bar height of 7b. One cycle (2b) comprises one bar and one space. The spatial frequency is expressed in line-pairs/mm (lp/mm), 1/(2b), in an object or image plane or as cycles/milliradian (cy/mr) when viewing a distant object. Note: The spatial frequencies generated by a single slit can be represented by a sinc function, which theoretically has infinite angular spatial frequency content.

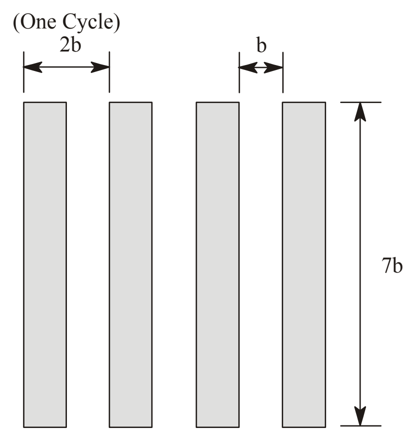


**Figure A-5. Standard Four-Bar Target**

**Square Wave** – A square wave is a periodic function which can be reduced to an infinite series of sine waves in the following Fourier series:

$$Sq(x) = Sin(x) + (1/3)Sin(3x) + (1/5)Sin(5x) + \ldots$$

When $0.6 < x < 0.9$ of the Nyquist limit, the aliasing of the third, and higher, harmonics of the series leads to an appearance of the image which contains false detail. Care should be taken when interpreting the appearance of 4-bar targets if the fundamental spatial frequency (x) of the target is in this range.

**Stop** – A stop is a physical aperture or diaphragm in an optical system that restricts the transmission of radiation through the system.

APPENDIX A. DEFINITIONS.

**Target to Background Temperature (Or Differential Target Temperature)** – For the purposes of this TOP, the target to background temperature is the temperature difference between a blackbody source (i.e., 'target') and a target plate (i.e., "background") in the type of thermal target used in MRTD and MDTD measurements.

**Target Plate** – For the purposes of this TOP, a target plate is a component of a thermal target used in MRTD or MDTD measurements. Typically, the target plate contains an aperture, or series of apertures, through which an observer can view a blackbody source, usually placed close to the target plate. The target plate is normally blackened to provide a high-emissivity, non-specular, homogeneous source at near-ambient temperature. Low-emissivity, specular target plates can be used where there are two blackbody sources, one seen through the target plate and the other reflected in the target plate.

**Thermal Contrast** – See Apparent Temperature Difference.

**Tilt** – Any angular deviation between the optical axis of an optical system and the axis of an element of the system.

**Trends** – A change in the background luminance of the raster caused, for example, by target inhomogeneities, shading, non-uniformity, floating baseline or, for scanning systems, 1/f noise, as illustrated in Figure A-6.

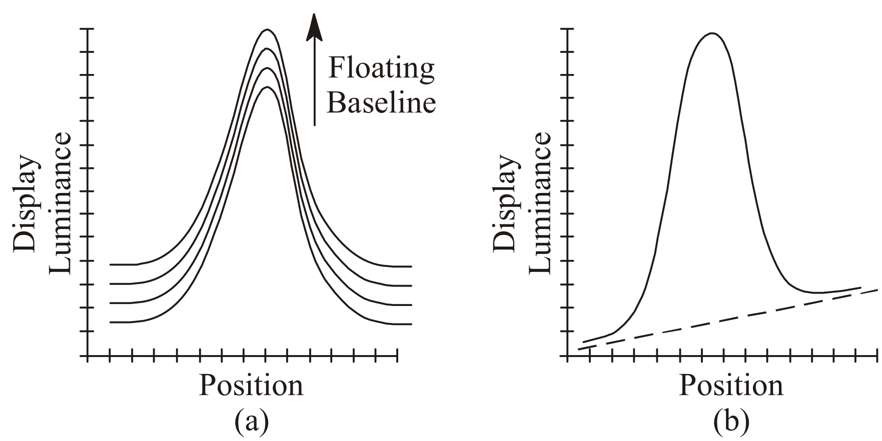


**Figure A-6. Trend Examples**

**Uncertainty Analysis** – For the purposes of this TOP, Uncertainty Analysis is the analysis and evaluation of all sources of error that contribute to the overall measurement error of a system property. These include, but are not limited to, the effects of the environment, the measuring equipment, the test item, and the operator. Particular care must be taken to discriminate between sources of error that give a random distribution about the true value and those which introduce a systematic bias to the results.

APPENDIX A. DEFINITIONS.

**Under-Sampled Imager** – A thermal imaging system is under-sampled when there are less than two samples per cycle at the highest spatial frequency transmitted by the system. Imagers using staring arrays, where the blur spot diameter of the optics is comparable with the detector linear dimension, are normally designed to be under-sampled.

**Uniformity (Display Uniformity)** – The measure of the variation of the luminance over the display area while observing a thermal target of homogeneous radiant emittance.

**Vignetting** – The loss of image illuminance within an optical system as a function of increasing off-axis angle. Any object that obstructs image forming rays can cause this effect.

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

The material in this appendix is provided to cover topics pertinent to EO/IR testing with an optical collimator system. Details and example calculations will be included for reference during test preparation and data analysis.

## SYSTEM INFORMATION

### General

1. Evaluating an infrared sensor by MRTD testing is a fairly straight forward process, although time consuming. Procedures and test methods are well defined, but it is the nuances of EO/IR physics, target configuration and analysis that can be perplexing.

2. Light given off by an object is perceived as the combination of reflected and emitted energy. Sensors are generally designed to measure the amount of light given off within a specific region of the electro-magnetic (EM) spectrum. The EM spectrum is simply how we discuss the energy (in the form of light radiation) output from a source. Figure B-1 below provides a picture of the various regions found in the EM spectrum. The primary difference between the different regions is the amount of output energy. Shorter wavelengths require more energy to be produced.

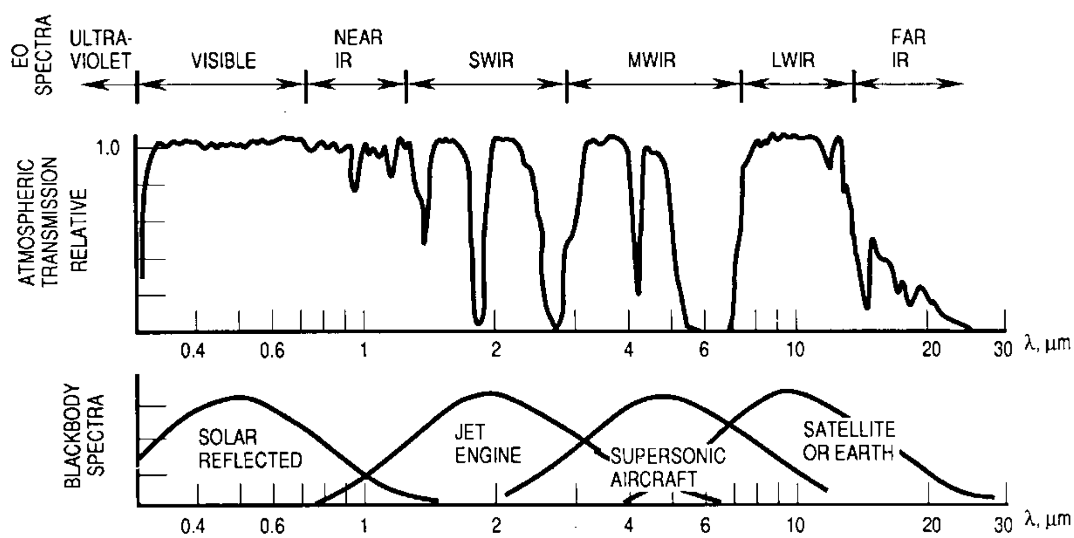


**Figure B-1. EM Spectrum (Introduction to Electro-Optical Imaging and Training Systems, K. Seyrafi and S. Hovanessian, Artech House, Boston, 1993)**

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

3. Radiation perceived by a sensor or human observer typically is transmitted through the atmosphere for some distance. Figure B-1 shows the effect of absorption by particles and water vapor found in the atmosphere. These dips in the transmission level are often referred to as absorption bands.

4. As shown in the lower portion of Figure B-1, most of what we perceive with our eyes is reflected light. An easy way to understand this is that with the lights turned off (i.e., no source), we do not perceive objects. To observe an object that emits radiation in the visible spectrum, the object must increase its energy level. To do this, the object must be heated up to over 700ºK. Again, to understand the difference between reflected and emitted light, turn off all the lights and observe the object heated to over 700ºK. The object will glow. All objects above a temperature of 0ºK will emit some energy (i.e., light) – even if our eyes (or sensors) don't perceive it.

5. A blackbody source is considered a perfect "emitter." Not a perfect "reflector" – that is a type of mirror. A blackbody is a source that emits all wavelengths. A source often used to model a perfect blackbody is the sun. It has a temperature of close to 6000ºK and it is a diffuse (uniform) source emitting energy at all angles. The sun emits energy across nearly the entire EM spectrum. This can be shown based on Plank's blackbody law that relates the absolute temperature of a body, the wavelength emitted, and its intensity.

**Equation B-1:**

$$M_{\lambda} = \frac{C_1}{\lambda^5 (e^{\frac{C_2}{\lambda T}} - 1)}$$

In this expression we have the following:

$M_{\lambda}$ = radiation emitted by the blackbody, per unit of surface area per unit wavelength. (watts/$cm^2$).
T = absolute temperature of the blackbody ($^oK$).
$\lambda$ = wavelength of emitted radiation.
e = base of natural logarithm = 2.718.

$C_1$ and $C_2$ are constants with values based on the unit of wavelength being used. If $\lambda$ is in centimeters then:

$C_1 = 3.741832 \times 10^{-12}$ watt-$cm^2$
$C_2 = 1.43848$ cm-deg

The effect of temperature is observed by plotting this relationship. Figure B-2 is a plot of this relation and represents the emitted blackbody energy for sources at different temperatures.

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

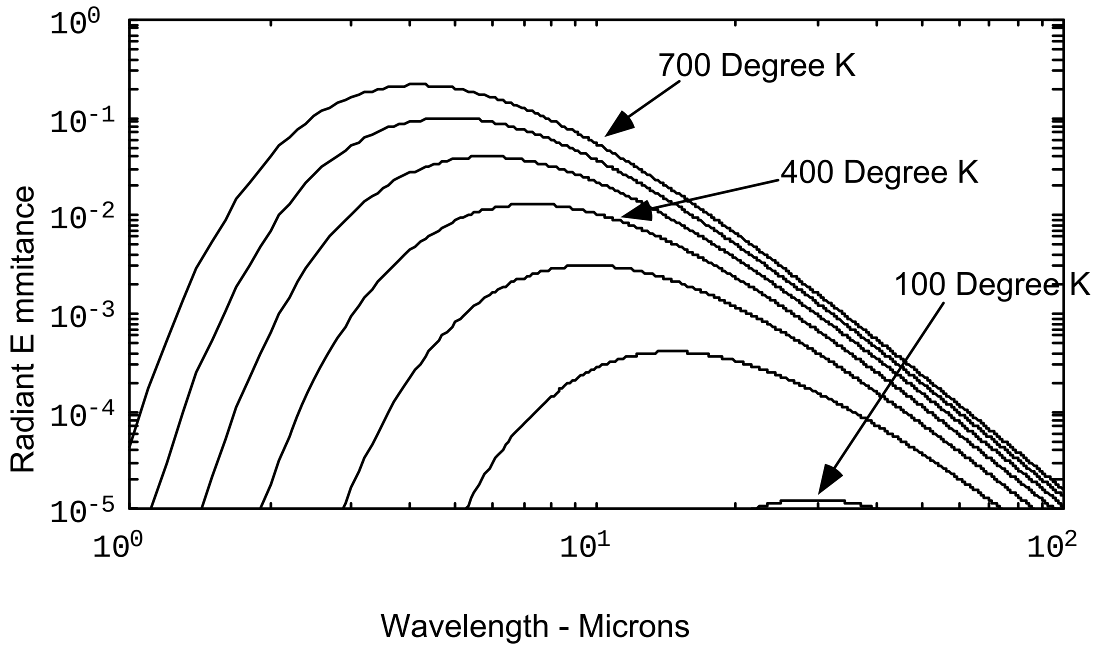


**Figure B-2. Plank's Law (Blackbody Radiation)**

6. For temperatures equivalent to the sun, the curve would show higher intensity and encompass more wavelengths. To determine the total radiation given off from a body at a given temperature, we can integrate the Plank blackbody equation for all wavelengths. This function is called the Stefan-Boltzmann Law.
Question: What is the correct spelling for "Stephan": see variance in para 6 (last line) and the equation below.

**Equation B-2:** $M = \varepsilon\sigma T^4$

Where the following apply:

M= rate of emission per unit area (watts/$cm^2$)
ε = emmissivity of radiating surface
σ = Stefan-Boltzmann Constant = 5.67 x $10^{-12}$ (watt/$cm^2 * K^4$)
T = Absolute temperature ($^{o}$K)

7. Emissivity is a critical parameter. It is the ratio of an object's radiance to radiance of a perfect blackbody at the same temperature and wavelength. Therefore, a perfect blackbody has an emissivity of 1.0 (ε = 1.0). All other bodies will have an emissivity less than 1.0 (ε < 1.0).

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

8. Because the sun does not fit in a box, manufacturers use another design. Most blackbodies use a metal plate that is indirectly heated to a given temperature. The critical features of these devices are the surface coating and their ability to radiate energy uniformly. The surface coatings are typically painted with a material that approximates the emissivity of a perfect blackbody ($\varepsilon \sim= 1.0$). In general, these coatings range from 0.9 to 0.99. When calibrating the blackbodies, these emissivity values are taken into account. It is important to note that these surfaces are critical in obtaining accurate measurements and care must be taken to avoid touching or damaging the coatings. Oils from fingers or airborne particles will, over time, degrade the performance of the blackbody.

9. Every object has a given emissivity. In general, when observing a set of objects with a sensor that detects a specific wavelength (e.g., 3-5 um) and the objects are at the same absolute temperature, then the difference in their appearance is attributed to emissivity. For example, looking at a runway with a FLIR sensor it is possible to observe not only the blacktop surface of the runway, but also the call letters or runway markings painted on the surface. If the paints used to create the runway markings had an emissivity value equal to the blacktop surface, it would not be possible to detect the markings because they are at the same absolute temperature as the blacktop surface. The apparent temperature of an object is directly related to its emissivity. A low emissivity will effectively lower an object’s apparent temperature value.

10. By differentiating Plank’s blackbody equation and setting the value equal to zero, then the result is the peak value of the blackbody curves. This is related as Weins law shown in Equation B-3 where Weins law relates the wavelength and temperature where maximum radiant existence occurs.

**Equation B-3:** $T\lambda_m = 2898$ (µm-K)

Where:

T = absolute temperature ($^oK$)
$\lambda_m$ = wavelength of maximum energy (microns).

11. With this relationship in mind, it is possible to determine that objects with typical terrestrial temperatures between 50F and 110F (283K – 316K) will emit the most radiant energy between (10um – 9 um). This is why LWIR sensors work so well for night vision systems they are observing the terrestrial objects that emit their maximum radiation at those levels. Consider objects such as plumes from aircraft engines whose temperatures typically range from 1000F – 1300F (800-1000K). Their peak radiant energy is between 3.6um – 2.9um which explains why most portable surface-to-air missiles (SAMs) operate in these lower bands – it provides opportunity for maximum signal-to-noise. Finally, as explained earlier, our eyes detect energy reflected by the sun. As indicated, the sun has a temperature of approximately 6000K; therefore, using Weins law, this indicates the peak radiation from

12. APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

the sun is at approximately 0.48 um. Keep in mind, these are peak values. Thermal objects, such as the sun or engine plumes, also emit energy across the wide spectrum described by Plank's blackbody law. This explains why the unaided eye is also able to observe light emitted by an engine plume. Even though the peak energy is in the 2-5 um band, a smaller amount of energy is transmitted in the visible band.

13. The blackbody sources used to perform MRTD typically operate at temperatures between 0C and 100C. Again, this range is nominal for most terrestrial objects and is what most acquisition FLIR sensors will be viewing. Objects outside this temperature range will typically saturate sensors.

14. For a blackbody, absorption and emission are complimentary optical terms. For the mirror, another piece of optical equipment used for MRTD testing, the complimentary optical tems referred to are transmittance and reflectance. The optical collimator used for MRTD testing consists of two mirrors. One is an optical flat mirror oriented at 45º and the second is a primary parabolic mirror used to focus the blackbody targets at infinity and collimate the light. A perfect mirror would reflect 100% of all light and every wavelength. Just as most objects have chacteristics of absorption and emission at different wavelengths, mirrors will have different characterisitics of transmission and reflection. These characteristics are often attributed to the types of coatings used to cover the mirror surfaces. However, the level of transmittance/reflectance can also be affected by the surface material (e.g., glass versus aluminum) and the angle of incidence the light makes with the surface. Knowing the effective collimator system transmission levels is critical as it affects the overall target apparent temperatures projected to the sensor. This value is the combined reflectance values of each mirror and the transmittance through the collimator path length (affected by atmospheric absorption). This value for the system is usually determined by careful measurement (see Appendix E: Determining Radiometric Efficiency), or a close approximation is obtained by multiplying the reflectance value for each mirror. In this case it is assumed that the path length is short enough to assume the transmission through the atmosphere is 1.0. The equation is as follows:

$$R_{sys} = R_1 \times R_2 = (0.99) \times (0.99) = 0.98$$

*Note: $R_1$ and $R_2$ relate the percent reflectivity in the waveband of the sensor being tested. Therefore, it is possible the total transmission level for LWIR testing will be different than MWIR testing. Also, be sure the transmission value relates the angle of incident.*

15. The collimator, shown in Figure B-3, is designed to minimize outside sources contaminating the test scenes. The housing encloses all the optics and minimizes the angle that allows reflection off the mirrored surfaces. Even though it is minimized, there is still a potential of external sources biasing the test data. For MRTD testing, this can be accomplished with baffling as well as keeping all personnel and non-ambient sources away from the collimator aperture. In some cases, the sensor being tested can act as a reflector sending a secondary image of the target back into the collimator that, in turn, may be

16. APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

reflected internally and contaminate test imagery collected. These internal reflections are often called “ghost” images because their intensity has been greatly reduced from the multiple reflections that have occurred. Often the test configuration does not provide methods to remove the ghost images, but typically a slight tilt of one optical element will move the reflection outside of the test scene.

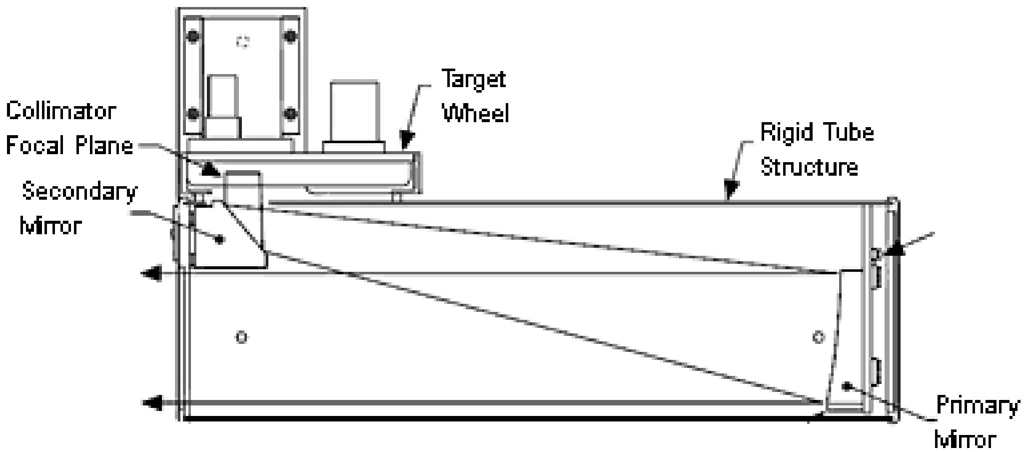


**Figure B-3. Collimator Design**

## Target Size Selection

17. By definition, the MRTD is a temperature value dependent on the spatial frequency of a target. Therefore, it is critical to understand the proper method of determining the spatial frequency of a target. The definitions for this document provide a description of a bar target’s fundamental spatial frequency. Because MRTD is performed normally viewing targets in the distance or through a collimator, the spatial frequeny is usually described in terms of cycles/milliradian (cy/mRad). In particular, one cycle comprises one bar and one space (see target diagram, Figure B-4). A standard 4-bar target is designed so that the bar height is always 7 times the bar width (a 7:1 ratio).

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

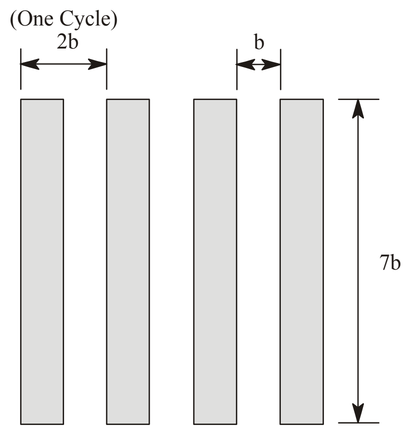


**Figure B-4. Standard Four Bar Target**

18. In general, MRTD testing requires targets ranging from low spatial frequencies to just past the system cutoff spatial frequency. If it is known that the system cutoff is 9 cy/mRad, how are the target dimensions (height and width) determined? Each cycle of the target will subtend an angle described by Equation 4.

**Equation B-4**: $$\theta = \frac{d_{target}}{fl_{col}} \quad \text{[unit Radians]}$$

19. Where $d_{target}$ is the width of one cycle (one bar plus one space) and $fl_{col}$ is the focal length of the collimator, the spatial frequency is then,

$$f_x = \frac{1}{1000}\theta \quad \text{[unit cycles/mRad]}$$

20. So, in the example, a target is required with a spatial frequency of 9 cy/mRad. If the collimator has a 60-inch focal length, then the target dimensions are as follows:

$$\theta = \frac{1}{1000 f_x} = \frac{d_{target}}{fl_{col}}$$

$$d_{target} = \frac{fl_{col}}{1000 f_x} = \frac{60}{1000 \times 9} = 0.00667 \quad \text{[inch]}$$

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

21. The width of one bar (BW) is half of a cycle ( $BW = \frac{d_{target}}{2}$ ). The bar height (BH), as previously mentioned, is 7 times the bar width ( $BH = 7 \times BW$ ). Therefore,

$$BW = \frac{0.0067}{2} = 0.0033 \text{ [inch]}$$

$$BH = 7 \times 0.0033 = 0.0233 \text{ [inch]}$$

22. Given the dimensions of a target, it is possible to use these equations in reverse to determine the spatial frequency as viewed through a collimator of a given focal length. Table C-1 (Appendix C) provides the spatial frequencies and measured bar dimensions for the 60-inch collimator used by ATTC.

23. Note, as the spatial frequencies become higher, the target dimensions decrease. For the 60-inch collimator, the issues become how small can a bar be physically cut out of the metal and is it too fragile? When targets begin to get this small, contamination also can become an issue. Dust or hair can block the openings creating false target projections. So, how can tests be performed on systems with system cutoffs greater than 10 cy/mRad? The solution is to use a longer focal length collimator. By increasing the collimator focal length to 120 inches, the target BW increases 2 fold to 0.0066 inch.

24. If a manufacturer has created a target with a measured bar height of 0.4196 inch, what is the spatial frequency for use in a collimator with a 60-inch focal length?

BH = 0.4196 inch

Therefore, $$BW = \frac{0.4196}{7} = 0.0599 \text{ inch.}$$

Since $$BW = \frac{d_{target}}{2}, \text{ then } d_{target} = 2 \times BW = 0.1198 \text{ inch,}$$

$$\theta = \frac{d_{target}}{fl_{col}} = \frac{0.1198}{60} = 0.00199 \text{ Rad}$$

$$f_x = \frac{1}{1000\theta} = \frac{1}{(1000 \times 0.00199)} = 0.5025 \text{ cy/mRad}$$

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

## OPTICS DESIGN

### Aperture Size Issues – Working Distance

1. Working with a collimator, it is expected that a point source will produce parallel light. An extended source, such as the MRTD target, can be considered as an infinite series of point sources at some discrete distance apart. When collimated, these discrete point sources result in parallel rays angled with respect to the relative distance away from the on-axis source. Figure B-5 shows how the rays from an extended source are related. This diagram illustrates a refractive collimator design, but the equations to follow will apply to a reflective collimator design.

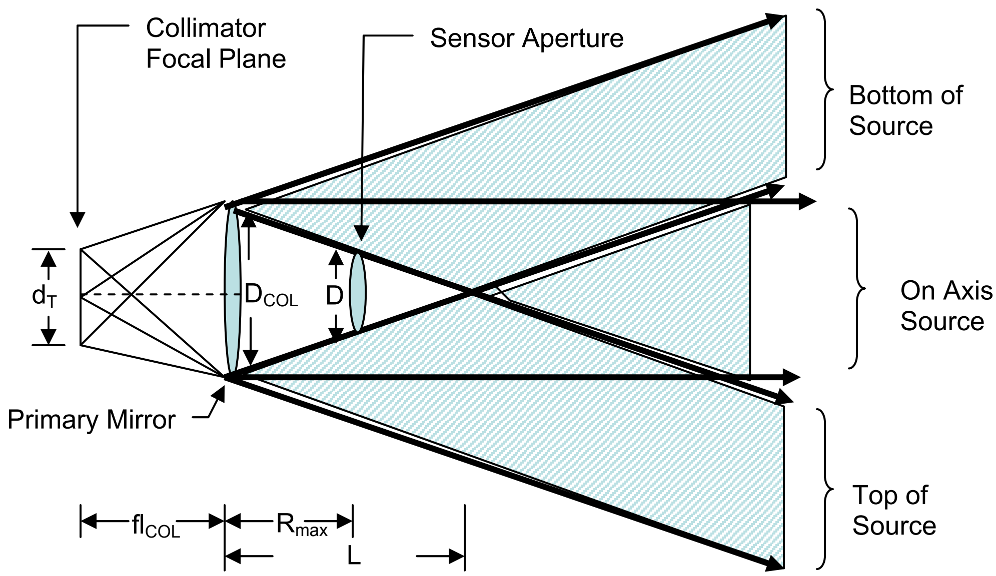


**Figure B-5. Collimator Working Distance**

2. To the right of the Primary Mirror, there is a cone formed where all the rays from the extended source can be collected. Outside this cone (shaded region) a sensor will not be able to collect light from some portion of the extended source. The result is a reduction in the target intensity, referred to as vignetting, or complete clipping of the target image. It is important during testing, that the sensor be located within this cone at the proper working distance. To determine this working distance, $R_{max}$, the focal length, diameter of the collimator aperature, diameter of sensor under test, and target extent must be determined. The focal length is defined by $fl_{COL}$. $D_{COL}$ defines the diameter of the collimator aperture while D defines the diameter of the sensor under test. The final item is the target extent or the largest dimension of the target. For square and rectangular targets, the largest linear dimension is the diagonal.

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

3. The maximum distance at which a sensor can be placed from the collimator is determined by the following equation:

$$R_{\max} = \frac{fl_{COL}}{d_T} \cdot \left(D_{COL} - D\right)$$

and

$$L = \frac{fl_{COL}}{d_T} \cdot \left(D_{COL}\right)$$

4. Based on the targets in Table C-1, the largest 4-bar target dimensions are (0.0998" *7)W x 0.7003" H or 0.7003" x 0.7003". The largest linear dimension is the diagonal ( $d_T = \sqrt{0.7003^2 + 0.7003^2} = 0.99037"$ ). The collimator aperture, $D_{COL}$, is a clear 12" diameter and the focal length, $fl_{COL}$, is 60". As an example, the Apache FLIR narrow field of view sensor has an approximately 8.5" clear aperture. Using these numbers results in a maximum distance of:

$$R_{\max} = \frac{60"}{0.99037"} \cdot \left(12" - 8.5"\right) = \frac{60"}{0.99037"} \cdot \left(3.5"\right) \cong 212"$$

5. This calculation is based on the extended target area defined only by the 4-bars. To include the entire target area, then $d_T$ = target diameter = 3". This results in a more conservative $R_{max}$ = 70".

***<u>Note</u>**: The focal length is the distance from the focal plane to the primary mirror. On most collimators, the primary mirror is located within the collimator housing a distance again equal to the focal length. The effective distance from the opening in the collimator housing is approximately $R_{max} - fl_{COL}$. For the above examples, with Rmax = 70", the collimator would have to be located within 10" (70"-60") from the sensor aperture to view the entire target area.*

## FLIR SENSOR DESIGN

### General

1. FLIR sensors are manufactured to a variety of specifications based on the intended use of the imaging device. The designs are often unique, based on the manufacturer's accepted trade-offs. The latest versions of sensor are often described by the following categories: MWIR vs. LWIR, Cooled vs. Uncooled, and Photon vs. Thermal. Each has advantages and disadvantages in their design.

APPENDIX B. COLLIMATOR SYSTEM DESIGN AND EO/IR TOPICS.

2. Manufacturers continue to design and create new concepts that combine sensors (e.g., sensor fusion) or use different detector materials to increase spectral bands into the Near IR (NIR).

3. Holst[2] provides an entire chapter (Chapter 2) dedicated to infrared system design, and the reader is referred to this source for additional information.

**System Cutoff and Nyquist Frequency**

4. The system engineer can estimate the Nyquist frequency, $f_N$, and system cutoff with some basic system information. The system cutoff is defined as the smallest value of the optical cutoff, $f_{OPTICAL\text{-}CUTOFF}$, the detector cutoff, $f_{DETECTOR\text{-}CUTOFF}$, and the Nyquist frequency.

5. The Nyquist frequency is defined as follows:

$$f_N = \frac{fl}{d_{CC}},$$

6. The variable, fl, is the effective optical focal length of the system. This may be different depending on the system field-of-view. The variable, $d_{CC}$, is the effective detector center-to-center spacing (detector pitch). Keep in mind this value may be different in the vertical and horizontal direction.

7. The optical cutoff frequency is defined as follows:

$$f_{Optical-Cutoff} = \frac{D_0}{\lambda} = \frac{Aperturediameter}{wavelength},$$

8. If $D_o$ has units of millimeters and $\lambda$ has units of micrometers, then $f_{OPTICAL\text{-}CUTOFF}$ will have units of cycles/ mrad. As an approximation, an average wavelength is used (e.g., for an 8-12 um sensor, $\lambda$ = 10 um).

9. For a detector angular subtense (DAS) defined as:

$DAS = \frac{d}{fl}$, d is detector size [units of milliradians]

Then,

$$f_{Detector-Cutoff} = \frac{1}{DAS}$$

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# APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

The material in this appendix is to provide a complete description and technical specifications of the RTC facilities and instrumentation used for performing MRT Tests.

## RTC FACILITIES

Laboratory

1. RTC maintains laboratory space that provides adequate environmental control for testing electro-optical systems. A standard 4'x8'x12" optical table with pneumatic isolation is available for tests requiring a stable, low vibration environment. Power is generally limited to standard wall power (120V); however, connections are available for some higher voltage systems (up to 240V).

Hangar

2. RTC maintains several hangar environments for testing installed sensor systems. This is the primary test environment for system testing at RTC. Environmental control is minimal. The hangar environments are located on an active flight line and vibration effects are not easily controlled. Tests requiring reduced lighting will require shrouds or optical tents. Optical equipment can be mounted on mobile tables or optical carts. As needed, optical breadboards can be used to provide a more stable mounting platform. A variety of power connections are available ranging from 120V to 480V.

## RTC INSTRUMENTATION

General

1. The following is a subset of the instrumentation available at RTC. This section will provide a general description of the major test equipment. More significant details will be covered within each associated test procedure. (Information should include FOV, size, resolution, height, waveband, etc.)

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

Athermal Collimator Test Set (ACTS)

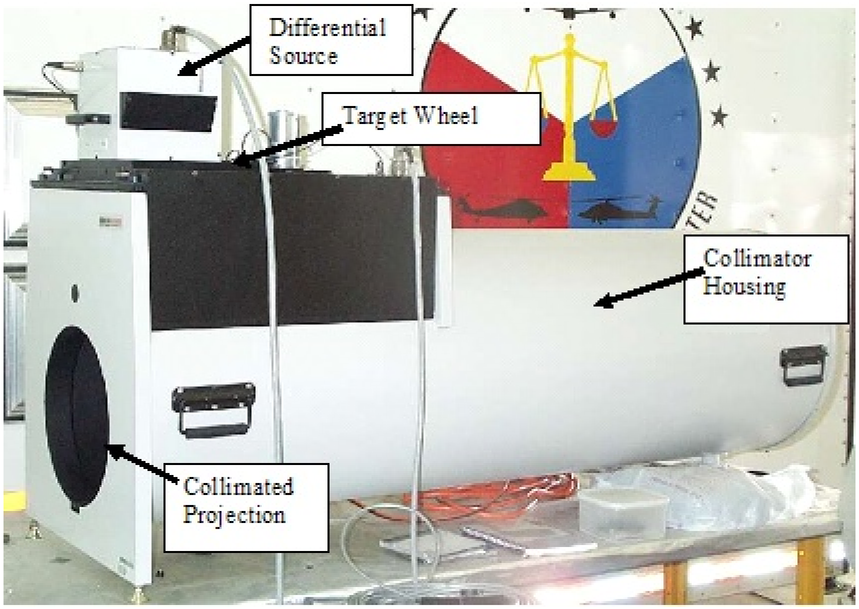



**Figure C-1. Athermal Collimator Test Set**

2. The Athermal Infrared Target Projector (Figure C-1) is a fully integrated test system used to verify the performance of infrared imaging systems. It is a thermally stable system specifically designed for use in a depot/hangar/field environment where the ambient temperature can vary widely. The system consists of three major components: collimator with differential source/target wheel/target set, controller, and a software system that includes a PC with frame grabber and software for automated testing of FLIRs, visible, laser and DVO systems. The system design allows for the future addition of laser test components for testing laser range finders and designators, and a visible source for testing visible sensor systems.

a. The graphite epoxy structure is lightweight and very robust; therefore, it is ideal for field portable applications or applications where it is moved from lab to lab often. Two handles on each end of the structure provide appropriate interface for 2-4 persons to move or carry the unit. CAUTION: The structure uses a 3-leg support design that provides some yaw, pitch, roll-type alignment; however, the collimator structure is slightly top heavy with the blackbody source mounted on top; and the 3-leg design can be unstable if not handled with caution.

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

b. The coefficient of thermal expansion (CTE) of the housing and mirrors are very low and extremely well matched. The CTE of graphite epoxy is $2.9 \times 10^{-6}$ in/ºC while the CTE for Pyrex is $3.2 \times 10^{-6}$ in/ºC. The match is ideal ($0.3 \times 10^{-6}$ in/ºC) with a CTE that is ten times lower than aluminum. Graphite epoxy structures provide an excellent trade-off between weight, cost, and robustness for both laboratory and fielded systems.

c. The target projector utilizes an off-axis Newtonian optical configuration for use in the visible and infrared.

d. System specifications:

(1) Clear Aperture: 12 inches

(2) Focal Length: 60 inches

(3) Overall Housing Length: 60.5 inches

(4) Surface Accuracy: ¼ wavelength at 633 nm

(5) Reflectance: > 93%, 3 to 14 microns

(6) Field of View: 2.86 degrees

(7) Maximum Laser Pulse Damage Threshold: > 140mJ @ 1.06 and 1.54 microns

(8) Focus: Maintain focus over 45 ºC to 105 ºC

(9) Weight: approximately 150 lbs

(10) Range Simulation: The target wheel design allows the use of custom targets to simulate discrete ranges from 50 meters to infinity. Each custom target will be designed with the position of the target plane set for the selected range.

APPENDIX C.  RTC FACILITIES AND INSTRUMENTATION.

**Thermal Differential Blackbody Source**

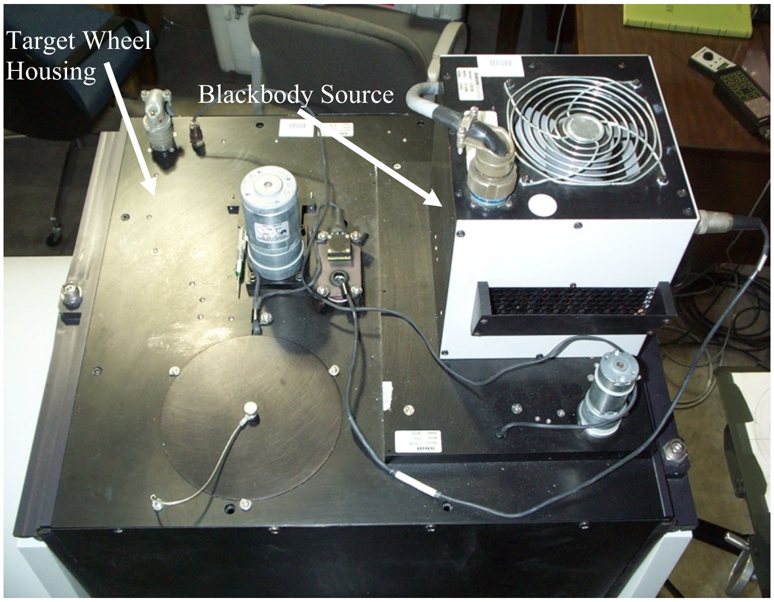



**Figure C-2.  Differential Blackbody**

3.   The model 14008Z Target Projector System features a model 2003 differential blackbody (Figure C-2).  The blackbody is located behind the target wheel (see Appendix B for additional details).  This blackbody determines the target feature temperature.

4.   The blackbody is connected to a digital controller.  The blackbody source can be controlled from the front panel of the controller (Figure C-3) when the blackbody is in Local mode, or via a remote hand-control panel (Figure C-4), or using the IEEE488 interface with a computer.

**Figure C-3 - Blackbody Source Controller**

**Figure C-4 - Blackbody Remote Panel**

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

5. The blackbody can operate in either absolute mode or DeltaT (Delta Temperature) mode. Absolute mode means that the commanded temperature of the blackbody source is the actual temperature of the blackbody source. In DeltaT mode, the source is controlled to a temperature that is deltaT degrees away from ambient.

6. System specifications:

a. Differential Temperature Range: -25 to 75 ºC

b. Absolute Temperature Range: 0 to 100 ºC

c. Emitting Surface Size: 7.62cm x 7.62cm

d. Temperature Stability: ±0.001ºC short-term, ±0.003ºC otherwise

e. Accuracy: ±0.01ºC delta T

f. Setpoint and Display Resolution: 0.001

g. Computer Interface: IEEE 488 standard GPIB

h. Emissivity: 0.985 ±0.015, 2 to 14 microns

i. Radiometric Differential Temperature: Automatic compensation for ambient temperature changes, optical transmission and emissivity

j. Hand-Held Remote Control: Hand-held panel for control of system functions.

k. Source Mounting: Removable from the target projector

Static Target Set and Target Wheel

7. A set of 24 targets is currently available. The targets are created by cutting out a target from a thin piece of metal and mounting the target to a larger piece of copper. The copper acts as a good heat sink and maintains the target at a constant ambient temperature. The targets are cutout by a process of etching or with laser cutting systems. Once the targets are cutout, an emissive paint is used to coat the surface of the target to provide a uniform target emissivity close to 1.0 (see appendix B for additional details). The target set includes 18 standard 4-bar targets between 0.3 Cycles/mrad to 10.7 Cycles/mrad. In addition, the set includes a large half-circle target used for MTF, NETD, and 3-D noise testing as well as an alignment target, a rectangular target, and three pinhole targets. Table C-1 and Table C-2 provide a detailed list of the individual targets with specific specifications. The drawing number is located on the back of every target for referencing in the future.

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

**Table C-1. Available Four-Bar MRTD Targets**

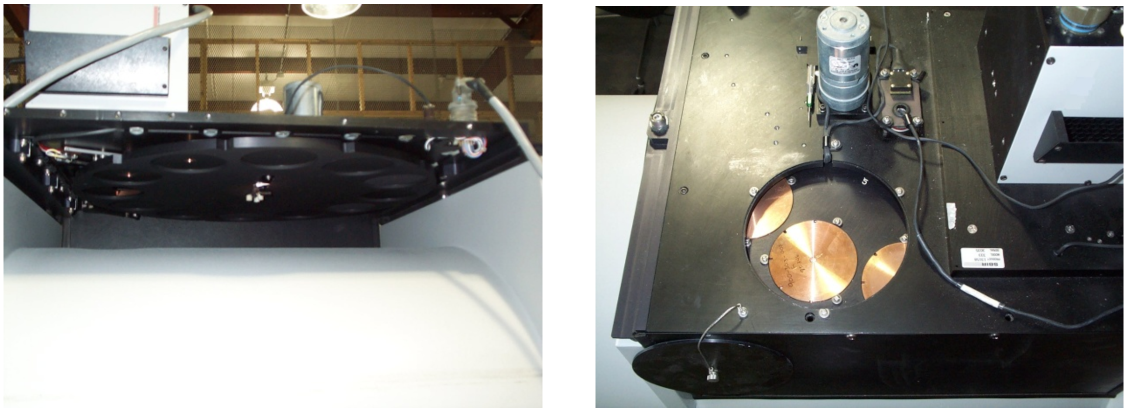
| Actual Freq (60" F.L.) | Drawing # | Serial # | Designed Width x Height | Measured Bar Width | Measured Bar Space | Measured Bar Height |
|---|---|---|---|---|---|---|
| 10.7143 | 913-005-025 Rev C | 75601 | 0.0026 x 0.0182 | 0.0028 | 0.0024 | 0.0184 |
| 9.0909 | 913-005-026 Rev C | 75602 | 0.0031 x 0.0217 | 0.0033 | 0.0029 | 0.0218 |
| 8.1081 | 913-005-057 Rev K | 85342 | 0.0036 x 0.252 | 0.0037 | 0.0035 | 0.0254 |
| 7.5000 | 900-199-320 Rev F | 58588 | 0.0040 x 0.0280 | 0.0040 | 0.0040 | 0.0281 |
| 6.6667 | 913-005-023 Rev K | 85341 | 0.0043 x 0.0301 | 0.0045 | 0.0041 | 0.0303 |
| 6.5217 | 900-199-319 Rev F | 58587 | 0.0046 x 0.0322 | 0.0046 | 0.0046 | 0.0323 |
| 5.6604 | 900-199-305 Rev E | 58585 | 0.0052 x 0.036 | 0.0053 | 0.0051 | 0.0361 |
| 5.3571 | 900-199-316 Rev E | 58584 | 0.0058 x 0.0406 | 0.0056 | 0.0060 | 0.0404 |
| 4.6154 | 900-199-315 Rev E | 58582 | 0.0067 x 0.0469 | 0.0065 | 0.0069 | 0.0467 |
| 3.7500 | 900-122-005 Rev M | 58577 | 0.0081 x 0.0564 | 0.0080 | 0.0082 | 0.0560 |
| 3.4483 | 900-199-314 Rev E | 58579 | 0.0089 x 0.0623 | 0.0087 | 0.0091 | 0.0621 |
| 3.0303 | 900-199-307 Rev E | 58583 | 0.0100 x 0.0700 | 0.0099 | 0.0101 | 0.0698 |
| 2.4793 | 900-122-018 Rev W | 85340 | 0.0120 x 0.0840 | 0.0121 | 0.0121 | 0.0835 |
| 2.0690 | 900-122-030 Rev M | 58581 | 0.0150 x 0.105 | 0.0145 | 0.0149 | 0.0143 |
| 1.5152 | 900-199-302 Rev NC | 58578 | 0.0200 x 0.1400 | 0.0198 | 0.0202 | 0.1398 |
| 1.0169 | 900-122-027 Rev M | 58580 | 0.0300 x 0.2100 | 0.0295 | 0.0305 | 0.2084 |
| 0.5034 | 900-122-021 Rev M | 58576 | 0.0600 x 0.4200 | 0.0596 | 0.0603 | 0.4196 |
| 0.3006 | 900-122-048 Rev V | 87165 | 0.1000 x 0.7000 | 0.0998 | 0.1002 | 0.7003 |

**Table C-2. Additional Miscellaneous Targets**

| Target Type | Drawing # | Serial # | Designed Width x Height | Measured Bar Width | Measured Radius | Measured Bar Height |
|---|---|---|---|---|---|---|
| Alignment | 900-198-002 Rev B | 85343 | 1.150 x 0.0251 | 1.1470 | | 0.0250 |
| Rectangle | 900-121-016 Rev N | 85345 | 1.341 x 1.341 | 1.3390 | | 1.3370 |
| Half Circle | 900-221-001 Rev A | 58586 | 1.375 | | 1.3800 | |
| Pinhole | 900-303-005 Rev G | 85346 | 0.00195 | | 0.0022 | |
| Pinhole | 900-152-004 Rev R | 85347 | 0.006 | | 0.0063 | |
| Pinhole | 900-303-008 Rev G | 85348 | 0.01575 | | 0.0160 | |

8. The model 14008Z Target Projector System features a model 316 12-position target wheel (Figure C-5). The target wheel is controlled from the front panel of the differential source controller (when the blackbody is in Local mode), or via a remote hand-control panel, or using the IEEE488 interface with a computer. The targets can be oriented horizontally, vertically, or at 45 degrees by rotating the target in the holder.

APPENDIX C.  RTC FACILITIES AND INSTRUMENTATION.



**(a)** **(b)**

**Figure C-5.  Target Wheel, (a) and Underside View, (b) - Top View**

9. System specifications:

   a. Target Positions:  12

   b. Target Size:  3-inch diameter

   c. Target Position Repeatability:  <0.001 inch

   d. Target Orientation:  0º, 45º, and 90º [manually selectable]

Power Lift Cart

10. The power lift cart is used to raise and lower the optical collimator system to achieve proper alignment with the system under test.   The cart is a double-scissor lift design (Figure C-6) that provides a collimator center line of sight range.  The max load capacity is rated for 500 lbs due to safety but is sufficient to carry the collimator (approximately 150 lbs) and additional test gear, as required.

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

**Figure C-6. Double-Scissor Cart**

AGEMA FLIR Sensor

11. The AGEMA FLIR Sensor is a Forward-Looking Infrared (FLIR) camera that operates in the long waveband (8-12 um). The camera (Figure C-7), a scanning system, uses a rotating polygon comprised of ten reflective facets to scan the scene onto the sensor.

**Figure C-7. AGEMA Camera and Storage Case**

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

**Figure C-8 - AGEMA Hand Controller**

12. System specifications:

a. Detector type: Multi-element MCT SPRITE

b. Wavelength: Long wave, 8-12 um

c. Cooling system: Integrated Sterling cooler

d. Cooldown time: 3-5 minutes

e. Image output: NTSC/VGA with 3:2 aspect ratio

f. Field of View (FOV) [Horizontal x Vertical]: Wide- 7˚ x 5˚, Narrow- 2˚ x 1.5˚

g. Instantaneous FOV [Horizontal]: Wide- 0.2 mRad, Narrow- 0.07 mRad

h. Near focus: Wide- 10 m, Narrow- 40 m

i. FOV switch time: 0.5 second
j. Weight: 22 kg

k. Physical size [L x W x H]: 700 mm x 260 mm x 270 mm

l. Power: 28 VDC

m. Operating environment: -30˚C to +55˚C

n. Resolution: 12-bit thermal resolution (4096 gray levels)

APPENDIX C. RTC FACILITIES AND INSTRUMENTATION.

Heavy-Duty Tripod

13. A heavy-duty tripod is used to mount the AGEMA camera. A ¼-20 bolt is provided with the access plate for mounting directly to the device.

**Figure C-9. Heavy-Duty Tripod**

APPENDIX D. COLLIMATOR OPERATIONS PROCEDURES

The material in this appendix is provided to augment system operation manuals. This appendix will highlight areas of importance or cover operational information not found in the operation manuals.

General

1. The Athermal Collimator and Blackbody is provided with a silver 3-ring notebook that is titled "TECHNICAL MANUAL 2000 SERIES." This contains the "Operating Manual" for the collimator, blackbody, target wheel and controller. This manual covers, in detail, the methods of initial setup, controller operation (e.g. menus, displays and manipulating system settings), remote operations, maintenance and repair, and calibration. Because the vendor manufacters multiple collimator configurations and uses various versions of their equipment, the manual does contain information that may not be relavent to the RTC configuration. In general, these differences are fairly obvious.

SETUP

Unpacking

1. While the collimator housing, the target wheel and the blackbody are three separate pieces of equipment, they are seldom used apart from one another. This simplifies the unpacking, because these systems are typically connected to one another at all times and function as a single unit. Figure D-1 shows the individual components as they are connected in the system and identifies the critical interfaces for these systems.

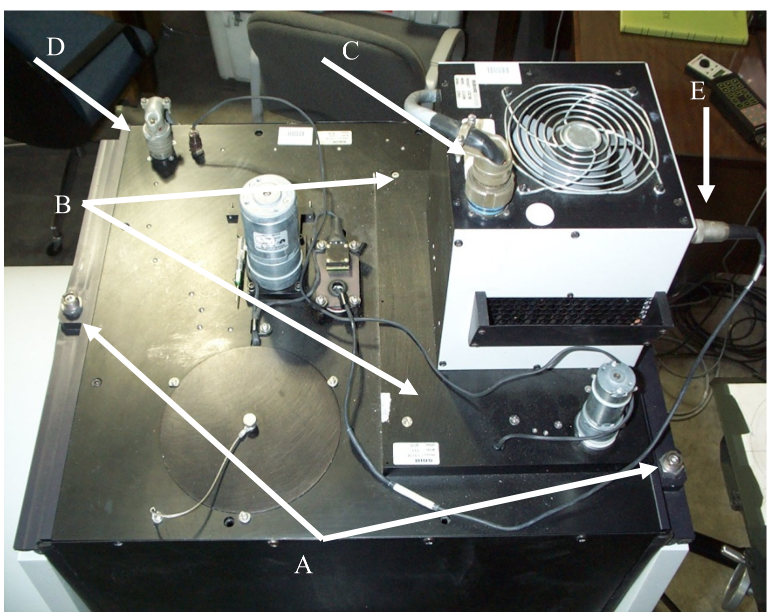



**Figure D-1. Interfaces for Blackbody, Target Wheel and Collimator**
(A – Bolts; B – Screws; C, D, and E – Connectors)

APPENDIX D. COLLIMATOR OPERATIONS PROCEDURES

2. The bolts, labled A, are used to mount the target wheel to the collimator housing. A total of 3 bolts are used (the third bolt is behind the blackbody in the picture). The bolt pattern provides a kinematic mounting capability that allows critical alignment of the bolts within the collimator housing.

*NOTE: It is imperative that no one remove the target wheel from the collimator. It has been aligned at the factory to be located at the focal plane. Do not adjust these bolts because it will affect the alignment and the collimating ability of the system.*

3. The screws, labeled B, are used to mount the blackbody to the target wheel surface. There are 4-6 of these screws that hold the blackbody secure. Alignment of the blackbody is not critical because it is designed to back illuminate the target. In this kind of configuration, the blackbody surface is de-focused on purpose to allow a more uniform source. The blackbody is usually removed only for calibration and for determining the collimator transmittance.

*NOTE: Beneath the blackbody plate that attaches to the target wheel surface are small metal spacers. Be sure to carefully lift the blackbody vertically so that the spacers do not fall down into the collimator opening. Also, once the blackbody is removed, it is suggested that a piece of cardboard be used to cover the blackbody opening to protect the blackbody surface. This surface should not be touched with anything as it will affect the emissivity. In addition, another piece of cardboard can be used to cover the opening and protect the mirror or other targets in the target wheel from dust and other items.*

4. The blackbody controller interfaces to the target wheel and the blackbody at the connectors labeled C and D, respectively. These cables and connectors are keyed and should present no issues for connecting.

5. The connector, labeled E, interfaces the blackbody to the temperature reference probe. The temperature probe is mounted inside the target wheel. This is a sensitive item and should only be handled when calibration is necessary (see section below on calibration).

6. Except for connectors C and D, the collimator system is stored and packed with these components connected to one another.

## Connections

7. The blackbody controller is connected to the blackbody source and target wheel using the two gray cables. These connectors are keyed and should not present any issue to connection. The blackbody controller also uses a remote panel that is connected to the front panel of the controller. All these connections should be made with power to the controller turned OFF. The only other connection required is to connect a power cord to the blackbody controller.

## APPENDIX D. COLLIMATOR OPERATIONS PROCEDURES

Checkout

8. The blackbody controller performs a self-test when power is applied to the system. The status display on the front panel provides messages on the LCD. This status window has four lines available for messages. Normally, the top line is blank. If the controller detects an error, then the letters “ERR” will appear on the top line. The fourth line of the status window will show either “BSY” or “RDY,” depending on whether the unit is busy or ready. When the system is ready, the operator can perform testing.

9. The only other checkout is to verify the collimator optics are still intact after any transport. This can be done by opening the front cover and visually inspecting the mirrors. Because they are protected in the collimator housing, these items are seldom an issue if the system has been handled with care.

### ALIGNMENT

Rough

1. The following diagrams provide a general overview of alignment concepts and expected image output. Observe the imagery from the SUT as it images one of the larger 4-bar targets or an alignment target. Compare with the expected image output below. Figure D-2 provides a view of the desired alignment where the line-of-sight for both the Athermal Collimator (AC) and the system under test (SUT) are co-aligned. Under image view, the blue circle identifies the content observed by the SUT. In the image view, the green circle identifies the content projected by the collimator. Figure D-3 shows the general effect of vertical and horizontal translation of the collimator system. Notice the target projected from the collimator does not appear to physically translate in either direction, instead the image becomes vignetted (shadow across the image). To understand this phenomenon, notice in the desired alignment case the rays from the extended source are collected by the SUT because its aperture lies within the working distance cone. As the collimator is translated, fewer rays are collected for some portion of the extended target. These diagrams highlight that vignetting is the primary phenomena observed when translation of the collimator occurs. Figure D-4 shows the general effect of panning or tilting the collimator. In these cases, the SUT observes a translation of the target across its field-of-view. These diagrams highlight that translation of the target is the primary phenomena observed when tilting the collimator (notice the vignetting is not as dark). Note that panning the collimator is linked to translating the collimator horizontally, and tilting the collimator is linked to translating the collimator vertically. Combined motion with close observation of imagery will be required to optimize the alignment.

APPENDIX D. COLLIMATOR OPERATIONS PROCEDURES

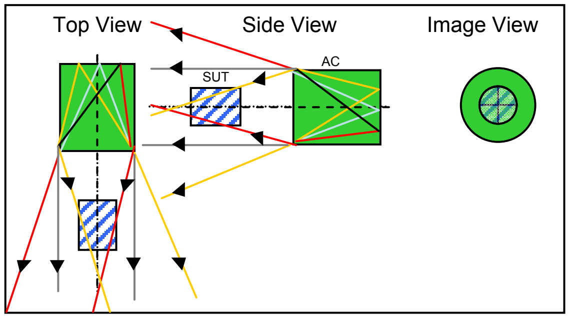



**Figure D-2. Desired Alignment**

APPENDIX D. COLLIMATOR OPERATIONS PROCEDURES

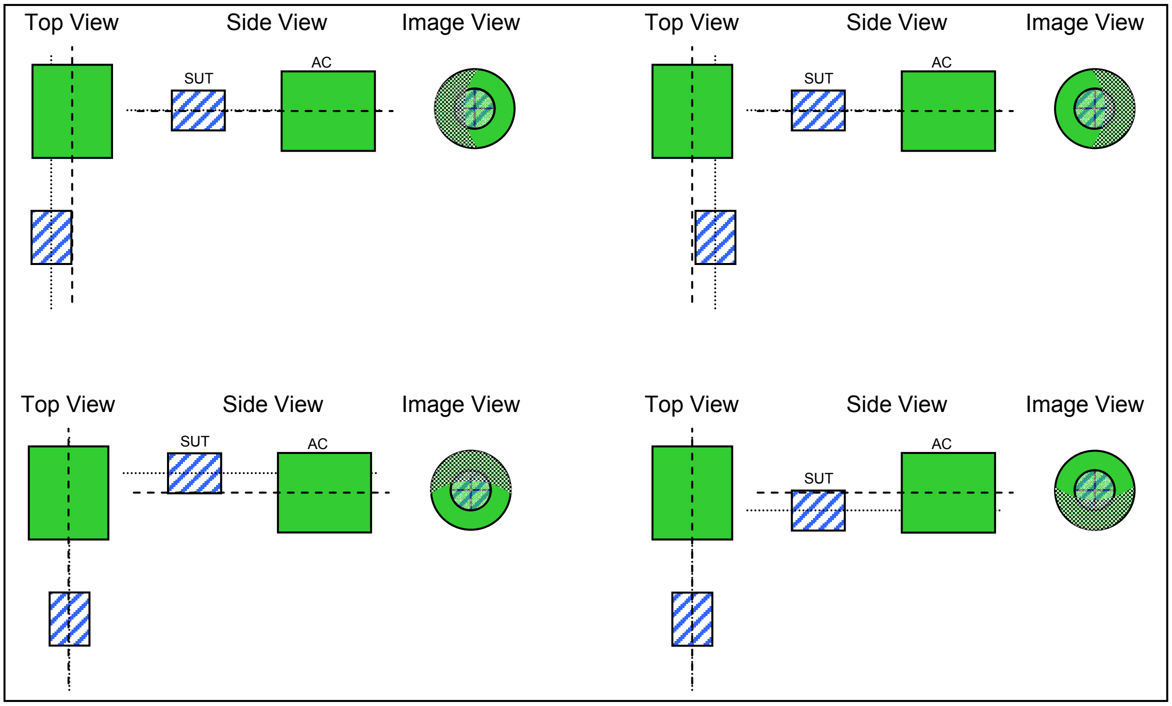



**Figure D-3. Collimator Translation**

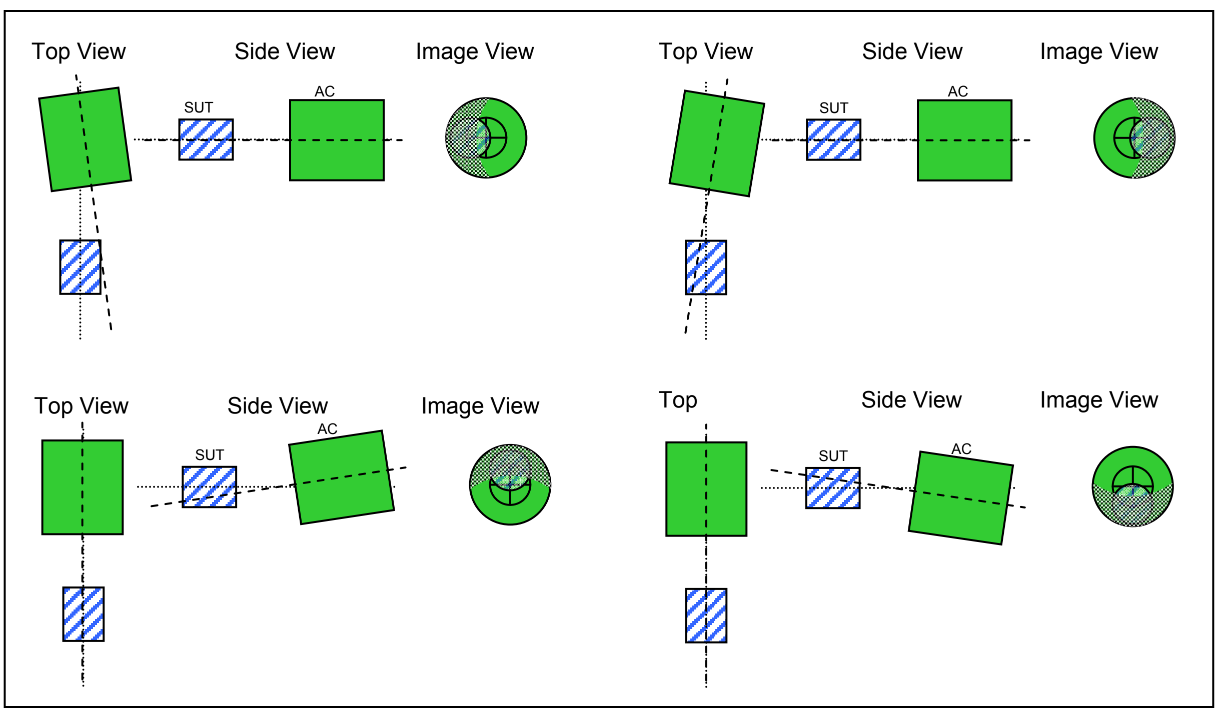



**Figure D-4. Collimator Rotation**

# APPENDIX D. COLLIMATOR OPERATIONS PROCEDURES

## RUN

Control

1. Front Panel. The operating manual provides sufficient details for operating the front panel controls of the blackbody controller. In general, the operator has the ability to display the measured absolute temperature of the blackbody source and/or the temperature of the ambient surrounding as defined at the target plate. The displays can also display the temperature difference between the source and ambient. In addition, the operator can also observe the target wheel position. Finally, another useful parameter is the radiometric temperature (absolute and relative) which defines temperatures based on effects of ambient background or thermometric fluctuations.

2. Remote Panel. The Remote panel operates similar to the front panel of the blackbody controller. The operating manual provides details for operator.

## TEARDOWN

Shutdown and Packing

1. Shutting down the system simply requires turning OFF the blackbody controller.

2. Before disconnecting cables or remote panel, make sure the power is OFF. Replace the cover over the front of the collimator entrance aperture.

3. If the collimator is mounted on the scissor cart, lower the collimator until the collimator legs are firmly against the scissor cart table top. Wedge Styrofoam under the collimator housing and apply straps across the collimator housing to secure the collimator for transport. The straps should be applied at the ends of the collimator where there is extra support. Do not overtighten the straps to avoid damage to the collimator housing.

# APPENDIX E. COLLIMATOR MAINTENANCE PROCEDURES.

The material in this appendix is provided to augment system operation manuals. This appendix will highlight areas of importance or cover maintenance information not found in the operation manuals.

## MAINTENANCE MANUALS

### General

1. The Athermal Collimator and Blackbody is provided with a silver 3-ring notebook that is entitled, "TECHNICAL MANUAL 2000 SERIES," which contains the "Operating Manual" for the collimator, blackbody, target wheel, and controller. This manual also covers maintenance, repair, and calibration. However, the manufacturer states there are no user serviceable components inside the blackbody or temperature controller. The manufacturer recommends the blackbody or temperature controller be returned if repair is necessary. Also, because calibration of the equipment requires specialized equipment, it is recommended that calibration be performed bythe manufacturer.

## GENERAL CARE

### Environment

1. The collimator was originally designed to operate in a hangar or laboratory environment. It is not intended for flight line or outdoor use. Care should be taken to avoid rain or other heavy moisture from contacting the system electronics, blackbody source, target wheel, and mirrors.

2. Dust or other small debris, while often unavoidable, should be treated as something to avoid when possible. Under normal conditions, no preventative maintenance or routine maintenance is required for operation. However, the operating manual describes routines for cleaning dust from blackbody fan ports, if necessary. Take great caution to avoid damaging the blackbody surface.

3. Dust and debris also affect the targets. When not mounted in the collimator target wheel, these targets should be kept in their protective cases. When mounted in the target wheel, avoid keeping the cover open any longer than necessary. Dust will settle on the target or even block some of the small target openings. This can cause errors when performing tests.

4. To minimize the effects of dust, it is recommended that all openings be covered when not in operation. When the system is stored for any length of time, a tarp or other covering can be placed over the blackbody source to minimize dust entering the fan ports.

### Sensitive Coatings

5. The collimator and blackbody equipment has been designed to protect the most critical or sensitive components; however, it is still susceptible to damage. In particular, any interaction

6. APPENDIX E. COLLIMATOR MAINTENANCE PROCEDURES.

with the targets, blackbody source, or collimator optics requires considerable care. Each of these components has special coatings that will adversely affect system performance if they are scratched, touched, or if they come in contact with moisture (e.g., do not breathe on any surface to remove particles). Additional insight is provided with each component below.

Changing or Rotating Targets

7. Always handle the targets by the edge to avoid touching the front surface of the target, which is distinguished by a flat black coating. The oils on fingers can change the emissivity of the surface. Even if you do not see any visible change after accidentally touching these surfaces, it is likely that in the infrared there will be a noticeable change. The manufacturer makes note that finger cots (latex-type covering for fingers) should be worn at all times when handling targets.

8. Take great care when removing the targets from their storage case or the target wheel. The tools used (e.g., screwdrivers, spanning wrenge, nuts and bolts) may cause damage to the targets if dropped on the target area. The high spatial frequency targets are especially susceptible to damage because the openings are very fragile.

9. Often targets mounted in the target wheel are wedged in tightly. This requires some practice to remove these items. When prying them out the targets may be susceptible to being brushed up against another hard surface which could cause scratching of the special coatings.

10. Again, exposure to dust and other debris should be avoided whenever possible.

Blackbody Source

11. When the blackbody source is scheduled for service or calibration, it requires the blackbody to be removed from the collimator housing. It can be detached by removing the screws holding to the target wheel. Care must be taken to lift the blackbody source vertically to avoid any spacers falling into the collimator housing.

12. When the blackbody source is removed, it is imperative that the coated surface be protected. Again, this surface can be corrupted by scratching, touching, or moisture. Therefore, cover the opening with a thick piece of cardboard and tape to the blackbody source. Make sure the cardboard cannot come into contact with the surface.

13. When the blackbody source is removed, the internal compartment of the collimator housing is left exposed. Cover this opening with another thick piece of cardboard and tape it to the collimator housing. This will ensure dust and debris are minimized.

APPENDIX E. COLLIMATOR MAINTENANCE PROCEDURES.

14. Once the blackbody is removed, the temperature probe must be disconnected from the target wheel. The location of this probe makes it difficult to remove and also increases the susceptibility of touching the surface of the targets or target wheel.

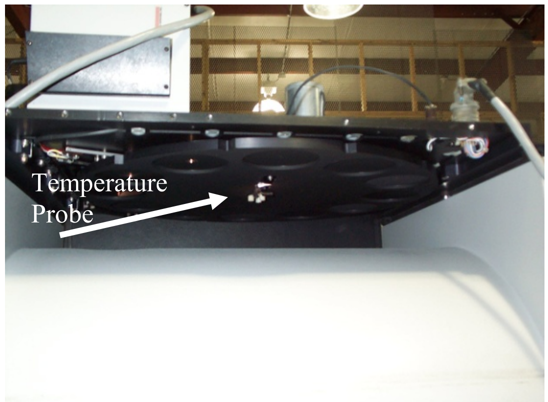



**Figure E-1. Temperature Probe**

15. Figure E-1 shows the location of the probe. It can be detached using a 90-degree angled ratchet with a Phillips screwdriver head. The space between the collimator housing and the target wheel is small and requires care to avoid touching the surfaces. Also, the temperature probe is coated with a white thermal grease that tends to be very messy. To completely remove the temperature probe, it must be passed up through a hole in the target wheel. This must be done carefully to avoid touching the probe and grease on any of the surfaces.

16. When replacing the probe after calibration, the steps are reversed. Keep in mind that probe calibration assumes proper coating of the thermal grease. Avoid removing any of the grease, if possible.

<u>Optics</u>

17. Because the optics (Primary Mirror and the Fold Mirror) are located inside the collimator housing, these components are well protected and require little to no maintenance. It is a good idea to visually inspect them for cracks or damage through the main collimator aperture. The coatings on the mirrors (protected silver) may degrade over time and should be inspected occasionally (every few years) by the manufacturer to ensure it will not affect testing.

18. The main concern for these components is when the blackbody source is removed from the collimator housing. During this time, the Fold Mirror is highly susceptible to damage by falling objects (e.g., nuts, bolts, or screwdrivers). Care should be taken when removing the blackbody source.

APPENDIX E. COLLIMATOR MAINTENANCE PROCEDURES.

CALIBRATION

Equipment

1. In the technical manual reference pertinent information regarding calibration and care are provided. Recommendation is for periodic inspection of the target and blackbody surfaces. If damaged or degraded, these surfaces can be re-coated. Cleaning of mirrors should be left to the manufacturer.

2. The manufacturer recommends the blackbody source be re-calibrated every year. This will include a general inspection and resurfacing of the source.

3. Returning the blackbody source is the most economical method for yearly calibration of the system. It is recommended that on occasion the system be returned for an overall inspection and system-level calibration. Many of the techniques used for MRT testing account for reduced transmission efficiencies or emissivity differences of target and blackbody coatings. But the test engineer should decide as to whether the scope of the test justifies the expense required to perform a full system inspection. The manufacturer prefers to perform these inspections at their own facility where specialized equipment and controlled environment is readily available if needed. However, options exist to perform evaluations and calibration of the collimator onsite.

Determining Radiometric Efficiency

4. Regardless of blackbody calibration, the radiometric efficiency needs to be determined for the specific test sensor waveband.

5. In general, the collimator transmittance can be determined by measuring the sensor response viewing a blackbody source and target through a collimator and then again without a collimator. Figure E-2 and Figure E-3 describe these two configurations.

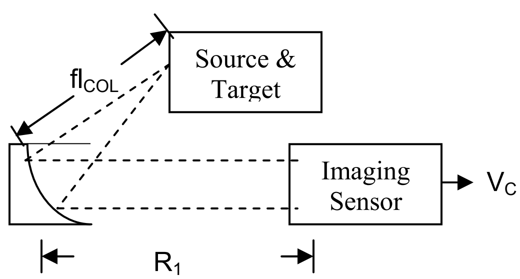



**Figure E-2. Measuring Transmittance with Collimator**

APPENDIX E. COLLIMATOR MAINTENANCE PROCEDURES.

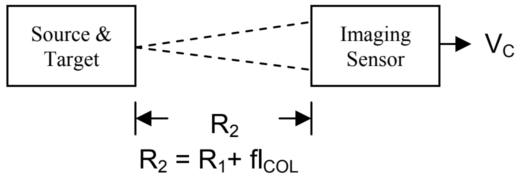



**Figure E-3. Measuring Transmittance without Collimator**

6. Measure imaging sensor responses, $V_c$, as shown in Figure E-4, for various Delta temperatures across the sensor's dynamic range. The response may be as simple as pixel counts from the sensor. Plot these values and determine the least-squares line fit to these data points as shown in Figure E-4. Next, remove the collimator and configure as in Figure E-3. Be sure the total path length remains the same between the two configurations (i.e., $R_2 = R_1 + fl_{COL}$). Also, ensure that the target covers the same pixels in the sensor for both configurations. This is to ensure that detector responsivities, cosine$^N\theta$ shading, and vignetting do not change. Ideally, the sensor will be able to focus on the targets without the collimator. Again, collect sensor responses, $V_{NC}$, and plot as shown in Figure E-4. The value of the collimator transmittance is simply the ratio of the slopes for the two lines, $T_{COL} = M_1 / M_2$.

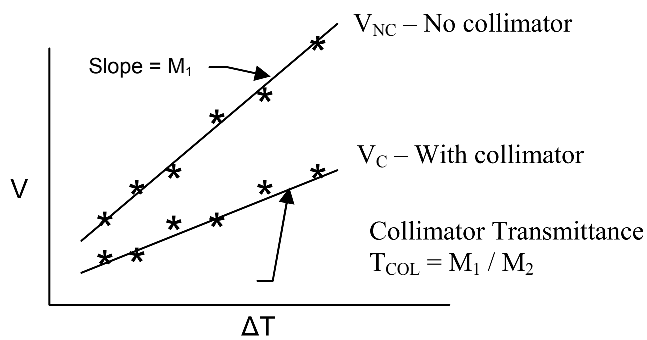



**Figure E-4. Sensor Response (With and Without Collimator)**

7. It is critical that the sensor used to measure the collimator transmittance have the same spectral response as the sensor under test. This means that the collimator transmittance will be dependant on what wavelength is being measured. Therefore, $T_{COL}$ will be unique for Long-Wave IR (LWIR) sensors and Mid-Wave IR (MWIR) sensors.

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# APPENDIX F. TEST DIRECTOR CHECKLIST.

The following checklist is provided for the test director to simplify and expedite test development and subject-matter research.

Pre-test

☐ 1. Obtain system specifications (e.g., FOV, Aperture, Focus range, etc.)

☐ 2. Develop test plan in accordance with ATTC Memo 70-12. [Review Appendix C: Test Plan.]

☐ 3. Verify availability and compliance of test facilities (e.g., hangar space, power, environmental conditions, lighting, safety, etc.). [Review Appendix C: Facilities.]

☐ 4. Identify test team availability (e.g., A/C crew, test subjects, data collectors, etc.).

☐ 5. Confirm personnel are trained as test subjects and/or operators of test equipment. [Review Appendix E. Collimator Maintenance Procedures.]

☐ 6. Ensure availability and calibration of test instrumentation. [Review Appendix C: Instrumentation.]

☐ 7. Create appropriate data sheets for recording test data. [Review Appendix F. Test Conditions.]

☐ 8. Conduct a pre-test brief for all test personnel on all aspects of the test program (e.g., purpose of each test, measurement requirements, preparation and operation of all test instrumentation).

☐ 9. Consider option to participate in a dry-run activity.

☐ 10. Consider time of day for performing tests. Some tests are affected by the diurnal cycle and heat loading.

☐ 11. If data to be collected is deemed classified, arrange for a proper storage facility.

☐ 12. If test activity is off-site, make proper arrangements for shipping test instrumentation. [Review Appendix C: Instrumentation.]

☐ 13. If test activity is off-site, coordinate access to any spare equipment/instrumentation. [Review Appendix C: Instrumentation.]

☐ 14. Develop a checklist of all equipment, tools, operations manuals, and datasheets required for testing.

## APPENDIX F. TEST DIRECTOR CHECKLIST.

Operations (Setup, Test, Shutdown)

☐ 1. Arrange for all necessary test equipment to be transported to the test facility.

☐ 2. Using equipment checklist, verify all test equipment and tools are available during test setup. [Review Appendix C: Test Plan.]

☐ 3. Connect all test equipment, as required, and verify functionality.

☐ 4. Perform alignment to system under test.

☐ 5. Verify test equipment and system under test have warmed up prior to test execution.

☐ 6. Provide data sheets to testers.

☐ 7. Begin test activities.

☐ 8. Collect test data, including environmental conditions.

☐ 9. Identify appropriate rest periods for the test subjects throughout the test period.

☐ 10. Upon test completion, turn OFF test equipment and test asset.

☐ 11. If testing is to occur on multiple days, cover or otherwise protect test equipment until testing resumes.

☐ 12. Using equipment checklist, verify all test equipment and tools are re-packed and prepared for return to ATTC facilities.

☐ 13. If collected data is classified, ensure it is secured properly.

☐ 14. If feasible, collect photographs of test equipment configuration for later review and documentation.

Post -Test

☐ 1. Conduct a post-test brief with all test personnel to discuss all aspects of the test program.

☐ 2. Record any lessons learned or issues that deviated from the original test plan.

☐ 3. Perform necessary analysis of data.

☐ 4. Produce Test Report in accordance with ATTC Memo 70-12.

# APPENDIX G. TEST PROCEDURES.

This section will provide direction for performing individual test procedures with the prescribed instrumentation. Information in this appendix assumes pre-test activities have been completed and the following instructions provide step-by-step methods to perform the setup, operation, and shutdown of the test equipment.

## ACTS

### Manual Minimum Resolvable Temperature Difference (Manual MRTD)

1. **General.** The purpose of this test is to measure the thermal resolution of a thermal imaging device as a function of spatial frequency for each test item field-of-view. Note that this reference is limited to analog or properly sampled thermal imaging sensors.

***NOTE***

*The Manual MRTD procedures, outlined in the ITOP, call for this test to be performed in a controlled laboratory environment. While ATTC has the capability to perform the test inside a controlled environment, the majority of tests are performed with the sensor installed in an aircraft. This configuration requires testing to be performed in a hangar environment with limited environmental controls. Therefore, test results obtained from these procedures should be compared against a degraded specification rather than a laboratory-based set of specifications. This is primarily due to environmental issues with measuring the MRTD of a sensor installed in the aircraft in a hangar. The procedures defined will maintain compliance with ITOP procedures except for few additional steps necessary to minimize environmental impacts.*

2. **Facilities**.

| Item | Description |
| --- | --- |
| Highbay/Hangar | Concrete pad<br>Limited environmental controls<br>Standard Power hookups |

APPENDIX G. TEST PROCEDURES.

3. **Instrumentation**.

| Device | Measurement Accuracy |
|---|---|
| Blackbody Source and Controller | A differential blackbody source with a thermal range of −25 °C to +75 °C from ambient. Santa Barbara Infrared (SBIR) model #: 11104, serial #: 2793. Model 920GIRW controller, serial #: 2971. Temperature: must be better than 0.1 of the thermal resolution specified for the test item, or 0.01 °C, whichever is larger. |
| Target Wheel | SBIR model 316, serial #: 3036. Holds 12 targets, each 3 inches in diameter. Contains a visible illumination source model 333, serial #: 3035, used for alignment purposes. |
| Collimator(s) | Diffraction limited, capable of covering the span of spatial frequencies specified for the test item, using the MRTD thermal targets. The waveband of operation must accommodate the waveband of the test item. The average radiometric efficiency (collimator transmission/reflection and atmospheric transmission) in the waveband of the test item must be known. The collimator aperture must be sufficient to overfill the entrance pupil of the test item at the collimator/test item separation (collimator working distance). (See appendix I: Aperture Size Issues.) |
| Collimated MRTD Thermal Targets | A series of 4-bar targets with standard 7:1 (height to width) aspect ratio.<br>Table C-1 ? provides OR Table C-1 and Table C-2 provide details on the individual targets available. |
| Lift Cart | Height adjustment. Using lag bolts attaching collimator to the lift cart provide fine adjustment as necessary for alignment. |

APPENDIX G. TEST PROCEDURES.

Setup

1. **Transportation**.

a. Arrange transportation of all equipment, tools, spares, and necessary documentation to test site. Use the checklist to verify availability.

b. Perform initial inspection of test equipment to verify no damage has occurred during transport. Ensure mirror in collimator is visibly intact. Verify no dings or dents are noticeable on the external housing that might imply harsh treatment. Check all cable connectors to ensure the pins are not crushed or damaged.

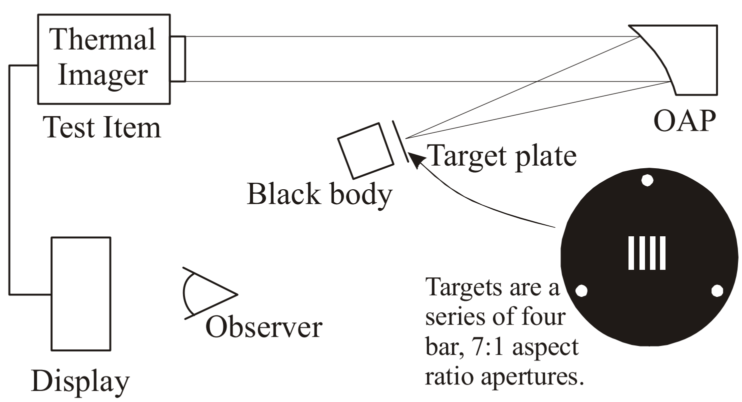


**Figure G-1. Typical MRTD Test Configuration**

2. **Assemble the Test Hardware**.

a. The collimator is mounted to the lift cart with 3 ¼-20 screws and is supported on each side by packaging used during routine transportation. During transport the lift cart is completely lowered. Provide power to the cart and lift the platform until the underside is accessible. Using a ¼-20 socket wrench, raise the collimator body until the support packaging can be removed. Retain this packaging for later transport. Attempt to place the collimator in the center of its motion range using the ¼-20 screws to allow for fine adjustments in either direction during the alignment phase.

b. Connect the blackbody source (attached to the top of the collimator housing) to the temperature controller. The supplied cable is keyed to only fit the J4 connector as labled on the controller. If this is not clear, refer to the SBIR Technical Manual for the 2000-Series device.

APPENDIX G. TEST PROCEDURES.

c. If the remote panel is to be used, connect it to the connector on the front panel of the temperature controller using the supplied cable. This connector should only be attached or detached while the power is OFF. It is not necessary to have the remote panel connected in order to use the other functions of the instrument.

d. Connect the target wheel (attached to the top of the collimator housing) [Nora deleted the word "see" preceding the following phrase) to the temperature controller. The supplied cable is keyed to only fit the J2 connector as labled on the controller. If this is not clear, refer to the SBIR Technical Manual for the 2000-Series device.

e. Connect a power cable to the temperature controller and apply power to the system from the front panel power switch.

f. When the Model 920 temperature controller is first turned ON, a series of tests are performed on the key components. As each test is performed, the POST (power-on self-test) code is displayed on the lower line of the main display. When the tests are complete, the current revision level of the major components are displayed in sequence. The status display (narrow window on the far left of the panel) will show either BSY or RDY depending on whether the unit is busy (changing the blackbody temperature or moving the target wheel) or is ready at the commanded setpoint and wheel position. The parameter wheel located on the front panel or the remote panel allows the operator to change the currently selected control. Pressing the Display button changes the current displayed parameter. Additional details about control parameters and front panel functions are found in the SBIR Technical Manual for the 2000-Series.

g. Verify the proper target set is loaded into the target wheel. Open the access panel on top of the target wheel. There is a spanning wrench and a detent tool located on top of the target wheel. These tools can be used to adjust and remove the targets as necessary. To remove targets, place one end of the spanning wrench into the target detent and pry gently to lift the target from its holder. If the target is tight, it may require prying alternating sides of the target to bring the target up evenly. The targets are created with a single detent slot that matches up with one of three holes located in the target wheel holder. These holes represent target configurations for the following orientations: 0º, 45º, and 90º. *WARNING: The target is coated with a black material that will be corrupted by any touching or rubbing. Touch only the side edges of the target. Also, the cutouts for many of the targets are very small, delicate and susceptible to damage or external contaminants like dust. Treat targets gently and avoid unnecessary handling*.

h. It is a good practice to allow the blackbody source to warm up/equalize for 15-30 minutes prior to collecting any data.

APPENDIX G. TEST PROCEDURES.

i. To view the collimator output, it is necessary to observe with an infrared sensor. The AGEMA/ Thermovision® or ™ camera is ideal for this application. Locate and setup the Quickset tripod. An allen wrench is provided on one of the tripod legs. Use this Allen wrench to loosen the set of ¼-20 screws located in the pan head that secure the camera-mounting plate. Remove the camera housing from the shipping container and verify that a mounting plate is attached to the bottom of the camera. It is secured with a set of four ¼-20 bolts and has a groove on each side of the plate that mates with the tripod pan head. The process of mounting the camera to the tripod typically requires two personnel (one to hold the camera and a second to guide the mounting plate into the pan head). Once the camera is mounted, secure it by tightening the two ¼-20 screws on the pan head assembly.

j. Accompanying the sensor will be a power supply, remote control and cables for interfacing to the camera. The cables are marked to coincide with labels on the rear panel of the sensor. The cables are also keyed to only function in the proper connector. One of the cables, labeled Video, provides camera output to an RS-170 monitor. The Power and Remote connections should be self-explanatory. A fourth connector, labled Digital, provides digital imagery but requires specialized hardware that is not available and, therefore, can be ignored. Connect the power supply and turn power ON using the switch located on the power supply. Lift the protective lid on the front of the sensor. Self-test imagery will be presented on the RS-170 monitor until the sensor's Stirling cooler reaches its appropriate temperature (usually 3-5 minutes). When imagery appears, the camera is ready for use. When viewing the collimator output, the sensor should be located near the front opening (aperture) of the Collimator. The operator may control the image settings with the remote control. Pressing the AUTO button will optimize the imagery for the given input scene. To switch fields of view, press the LENS button. On the bottom of the RS-170 monitor is a bar indicating focus position. Adjust focus using the up/down arrows labeled FOCUS.

> *NOTE: Focus settings are different for each field of view and must be adjusted independently. The optimal focus position for objects at infinity is when the indicator is slightly left of the bar graph marker for infinity focus.* For detailed information on control features, see the Thermovision Operator's Manual.

3. **<u>Prepare the Environment</u>.**

a. For laboratory testing:

(1) The laboratory ambient temperature should be set at the recommended ambient background temperature for the test item and maintained to control residual drift. Steps must be taken, by shielding or by other means, to avoid significant local background temperature variations or transient fluctuations (e.g., air ventilation, open doors, and personnel motion).

(2) Ensure the laboratory can be darkened to minimize glare. This requires dimming lights and blocking windows or other sources of light.

APPENDIX G. TEST PROCEDURES.

b. For hangar environment testing:

(1) *NOTE: The ITOP does not describe MRT test procedures within a hangar environment. These steps are defined to mitigate as much of the environmental concerns as possible while operating in a hangar.*

(2) Make all attempts to control and maintain the ambient background temperature as recommended for the test item. If temperature conditions cannot be controlled, then record ambient temperature values during each MRT measurement. This is important because ambient temperature changes can affect the apparent DeltaT measurements observed (e.g., a 1 ºC drift in ambient can appear as a 0.02 ºC DeltaT change for measurements in the 8-12 um region). Further insight on this phenomenon can be found in Appendix I: Apparent Temperature. If temperature variations cannot be controlled artificially, consider testing during a time of the day where thermal fluctuations are at a minimum. Consult diurnal cycle tables for your location and test during those times of least temperature variation. In a hangar, limit exposure of the test equipment to air currents from open doors, air conditioner vents or personnel moving about the system under test.

(3) Minimize vibration induced on the collimator or system under test. Some hangar environments are located near areas of traffic from heavy equipment. Again, consider performing tests at a time when the traffic is minimized. Vibration is also induced by personnel occupying or egressing from the system under test. Make notes of any incident that may affect the validity of data and provide time of event for correlation during analysis.

(4) Ensure the viewing area (e.g., cockpit) can be darkened to minimize glare. This requires covering all cockpit windows and dimming any unnecessary instrument panels.

4. **Power-up system under test.** Power up system under test in accordance with that systems operator's manual.

5. **Alignment of test equipment.**

a. Determine the working distance allowed for the given FOV based on the system under test specifications and the collimator specifications (see Appendix I: Aperture Size for calculation methods). Ensure the collimator can operate within the working distance.

b. Move the lift cart/collimator to a position as close as possible to the system under test without raising risk of impact or damage to either system. This will provide additional tolerance in alignment and minimize possible reflections from surfaces in or on the collimator.

APPENDIX G. TEST PROCEDURES.

(1) An ATTC fabricated circular plate (fig G-2) with a small mag flashlight fastened to the center can be attached to the front end of the collimator and used to aid in intial alignment of the the collimator FOV with the system under test. For critical alignments, a laser pointer can be fastened to the circular plate as shown in figure G-3.

Figure G-2. ATTC plate with flashlight Figure G-3. ATTC plate with laser pointer

c. Determine if the system under test uses a common optical path for each field of view. If not, keep in mind that alignment must be optimized for each field of view individually.

d. Select a FOV for the sensor and place the sensor in a fixed-forward position. If the sensor does not have the ability to fix the line of sight to one position, alignment may only be approximate or may float. With the sensor fixed forward, determine the general line of sight with respect to horizon. If the system under test line-of-sight is parallel to the ground, alignment will generally be uncomplicated. If the SUT is looking slightly down or up, then the collimator will most likely require additional adjustments to accommodate the tilt in the sensor LOS.

e. Raise the cart so the center of the collimator aperture is even with the center of the SUT aperture. Move the cart side-to-side until the center of the collimator aperture is even with the center of the SUT aperture. This can be done initially by approximation as you look externally at the apertures. Once the systems are closely aligned, use imagery from the SUT to complete alignment.

f. Set the blackbody source to a high deltaT value of 5 ºC. Using a large 4-bar target or other alignment target, observe imagery output from the SUT and roughly align the collimator until target imagery is observed.

g. The alignment process is an iterative process. Diagrams in Appendix G show the general affects of alignment motions (vertical, horizontal, pan, and tilt). Use these concepts to move the collimator system until the optimal alignment is created.

APPENDIX G. TEST PROCEDURES.

h. Begin the iterative process. Pan the collimator until the target is centered in the SUT output imagery. Then move the collimator horizontally, both left and right, and observe the level of vignetting. Position the collimator so that vignetting is minimized. If the target is off center, pan the collimator to re-center the target; then, repeat horizontal translation to minimize vignetting. Do this process until vignetting is minimized and the target is centered.

i. Tilt the collimator until the target is centered in the SUT output imagery. Then move the collimator vertically, both up and down, and observe the level of vignetting. Position the collimator so that vignetting is minimized. If the target is off center, tilt the collimator to re-center the target; then, repeat vertical translation to minimize vignetting. Do this process until vignetting is minimized and the target is centered.

j. Recheck horizontal alignment; if significant adjustments are made, repeat the alignment process for vertical direction.

> *NOTE: The capability for alignment of the collimator mounted on the lift table is limited. Vertical translation is controlled by the lift table and may be difficult to incrementally raise and lower. Horizontal translation is difficult because the entire cart must be moved. Until horizontal translation slides are incorporated into the design, the process will require a back-and-forth motion of the cart that may or may not improve alignment. Panning the collimator will be done by swinging the handle end of the cart left and right. True panning requires maintaining a single point of rotation (preferably collimator's front aperture will remained fixed), unfortunately, swinging the handle end of the cart will likely move the front end some amount. Tilt is possible, but the amount of tilt may be limited by the turn screw length and may require multiple turnscrews to achieve level of tilt desired. Bottom line, alignment will be a best effort process and may be tedious due to existing configurations.*

k. The following is a process to use as a sanity check on your alignment. Change to the large crosshair target. This target is symmetrical about its center. If the SUT allows measuring the number of pixels on target, observe the length, from the center, of each leg of the crosshair target. If the sensor cannot count pixels, then visually observe the lengths for any gross differences. If there is a difference, this could be due to considerable tilt in the alignment and may require adjustment of the collimator line of sight. *NOTE: Differences in the lengths of the legs could also be due to poor optical quality of the sensor or distortion in the display system (e.g. using 16:9 aspect ratio instead of 4:3 aspect ratio). This is not an absolute check but may provide additional information that could be caused by alignment or some other phenomena.*

APPENDIX G. TEST PROCEDURES.

l. If multiple sensor fields of view will be tested, verify collimator alignment in each sensor FOV. If targets do not appear co-aligned from each FOV, the sensor could have poor boresight; however, more likely the sensor does not use a common aperture (common LOS) for each FOV. If the sensor does not use a common aperture for all FOVs, alignment will be required for each. Consider your test agenda so that you minimize moving the sensor alignment unnecessarily.

6. **MRT data collection.**

a. The temperature difference between the blackbody source (target) and the target plate (background) provides the thermal contrast. The temperature difference between the blackbody seen through the apertures in the target plate and the solid parts of the target plate is the target to background temperature difference (i.e. DeltaT). The fundamental spatial frequency of the bar target is defined by the period of the four-bar target and collimator focal length (see Appendix I: Target Selection).

b. The MRTD is the minimum target to background temperature difference at which the four-bar target can just be resolved by a trained observer. A Forward MRTD is measured with the blackbody temperature above the background. A Reverse MRTD is measured with the blackbody temperature below the background.

c. The Forward and Reverse MRTD values are measured at different spatial frequencies by using a selection of standard four-bar targets. The standard four-bar target patterns range in size to represent spatial frequencies typically ranging from $0.1F_N$ to just beyond $F_N$, where $F_N$ = Nyquist frequency (cy/mr).

d. The temperature difference between the background and the blackbody is varied between −10°C and 30°C for the Forward and Reverse MRTD. The target plate is placed at the focus of a collimator so that the correct spatial frequency is presented.

e. The horizontal MRTD is measured with the vertical bar pattern placed in the on-axis position (OA). If required, targets can be manufactured to provide off-axis FOV positions. These can be defined as shown in G-4, where OA = on-axis and UR = upper right, etc. The horizontal separation between positions UL and UR or LL and LR and the vertical separation between positions UL and LL or UR and LR will typically subtend 80% of the field-of-view.

f. If required, this measurement can also be made with horizontal bar patterns for Vertical MRTD.

APPENDIX G. TEST PROCEDURES.

## 7. Test Procedures

a. Use an observer who is considered / recognized as trained in the area of resolving 4-bar targets to determine the MRTD. The observer's visual acuity should be corrected 20/30 or better with corrected astigmatism.

b. Prior to any test with a new FOV, the observer should verify and set the focus using the sensor's standard operating procedures to the smallest collimator target pattern to be used during testing.

c. While viewing the target on the display in a dark-adapted environment, permit the observer to adjust all control settings and background illumination conditions for optimum image quality. Once set, the white-hot/black-hot polarity setting should be recorded and maintained as best as possible for the duration of the test. The target plate (background) temperature shall be homogeneous and close to the laboratory ambient temperature. Record the laboratory ambient temperature and the target plate temperature (if different from ambient). For hangar environments, record the target plate temperature (i.e. ambient temperature) at every reading. This will provide additional data for analysis if temperature drift occurs during the experiment.

d. The criterion to be used for the MRTD measurements is that it should be possible to just resolve 75% to 100% of the area of the bars and spaces between the bars (not just some modulation) on the display, 50% of the time. It is not necessary that the whole of each bar be visible at the same time.

e. MRTD is calculated to give apparent temperature difference values and is given by $MRTD = \eta\Delta T$; where $\eta$ is the radiometric efficiency and $\Delta T$ is the actual target to background temperature difference (°C). See Appendix H for additional information on calculating radiometric efficiency.

APPENDIX G. TEST PROCEDURES.

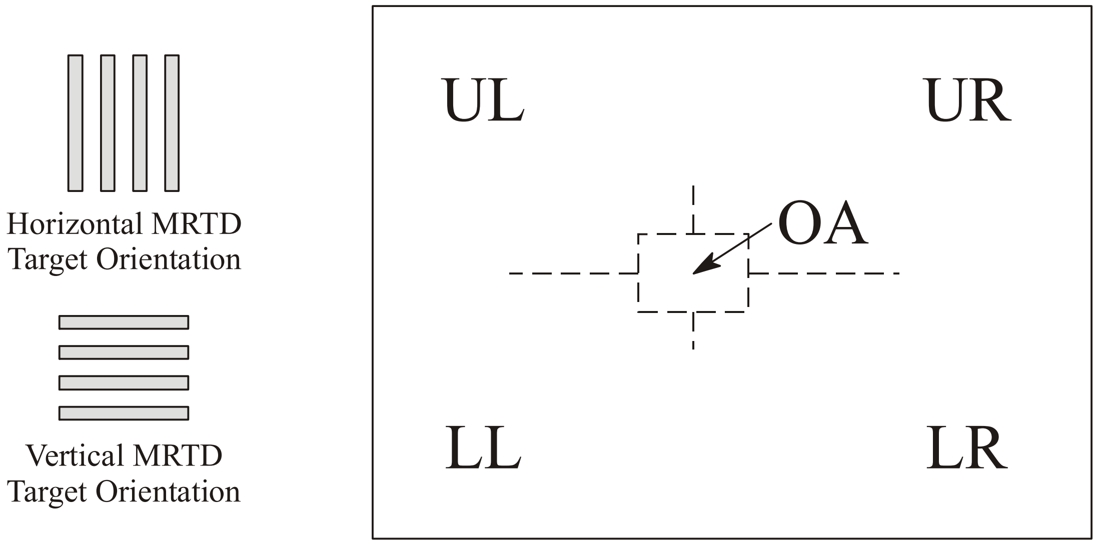


**Figure G-4. Horizontal and Vertical MRTD Target Orientation and MRTD FOV Positions**

f. For each combination of target spatial frequency, orientation and field-of-view position (G-4), perform the following operations to obtain values for Forward and Reverse MRTD.

(1) Adjust the temperature of the blackbody to make the target bar pattern temperature much higher than the target plate (background) temperature so that the bars are clearly distinguishable.

(2) Optimize the test item display controls to obtain the best image. The test item position may be slightly adjusted in pitch and/or yaw to obtain the maximum visibility of the image. Any aliasing effects (e.g., changes in bar width or spacing) should be noted and, if possible, photographed.

(3) Change the blackbody temperature from a temperature higher than the target towards the temperature of the target until the bars are clearly unresolvable.

(4) Slowly change the temperature of the blackbody away from the temperature of the target to a temperature higher than the target.

(5) Calculate and record the minimum apparent temperature difference between blackbody and background for which the target bar pattern is just distinguishable (Forward MRTD).

APPENDIX G. TEST PROCEDURES.

(6) Adjust the temperature of the blackbody to make the target bar pattern temperature much lower than the background and clearly distinguishable.

g. Repeat steps b through e, except record as the Reverse MRTD.

h. Calculate the MRTD by taking half the difference of the Forward and Reverse MRTDs.

i. Where multiple observations are made by a single observer, calculate and record the arithmetic mean MRTD of the observations.

j. If more than one observer is required, repeat the test as described in paragraph 4.1.4.d of the ITOP for each observer.

k. Calculate the geometric mean of the MRTD for the observers and record as the overall geometric mean MRTD at each combination of target spatial frequency, orientation and field-of-view position. (The geometric mean is used because the observer-to-observer variability typically follows a log-normal distribution.) Typical observer-to-observer variations in MRTD are shown in Figure G-5.

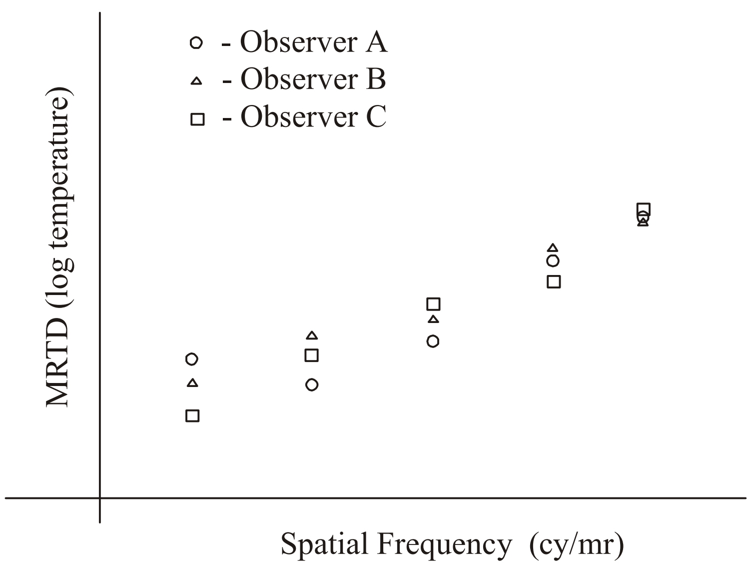


**Figure G-5. MRTD Observer Variation**

## 8. Data Required

a. Number of observers

APPENDIX G. TEST PROCEDURES.

b. Radiometric efficiency

c. Test item field-of-view

d. Target plate temperature (if different from ambient)

e. Lab ambient temperature

f. Target orientation

g. Target spatial frequencies used

h. MRT values for all targets and orientations for each observer. Analysis will be performed to calculated geometric mean of MRTD values for each combination (arithmetic mean if one observer).

## 9. Presentation of Data

a. For each target orientation, provide a table of the calculated MRTD values as illustrated in Table G-3. MRTD Measurements.

**Table G-3. MRTD Measurements**

| MRTD MEASUREMENTS | | |
|---|---|---|
| Number of Observers: | | Target Plate Temperature: |
| Target FOV Position: | | Test Item FOV: |
| Lab Ambient Temperature: | | Radiometric Efficiency: |
| Spatial Freq (cy/mr) | Overall Mean MRTD at FOV Position | |
| | Horizontal MRTD | Vertical MRTD |
| 0.1 | | |
| ⋮ | | |
| 10 | | |

b. For each target field-of-view position, provide curves of the horizontal and vertical MRTD as a function of target spatial frequency, as illustrated in Figure G-6. The curves are fitted to the overall mean values from Table G-1.

APPENDIX G. TEST PROCEDURES.

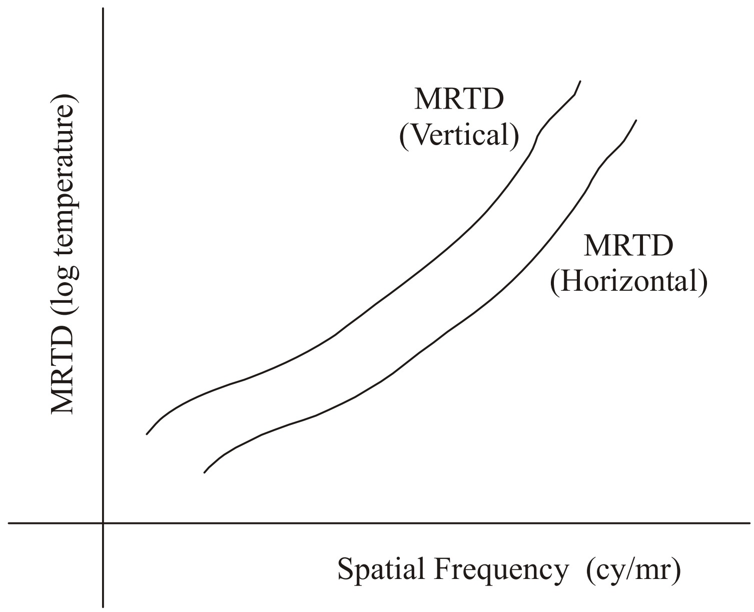


**Figure G-6. Typical MRTD Curves**

# APPENDIX H. DATA ANALYSIS.

The material in this appendix is provided to identify standard sources of error involved in MRT testing. Methods are described for handling the error sources and documenting the results. Also, this appendix will provide insights into evaluating and understanding MRT data.

## GENERAL

### Uncertainty Analysis

1. The measurement uncertainty is the result of a number of systematic and random sources of error. These include, but are not limited to, the following: the environment, the measuring equipment, the test item, and relevant assumptions made during the test program.

2. It is recommended that a text on uncertainty analysis for MRT testing, such as Chapter 12 of Holst (ref A2) and Chapter 9 of Biberman (ref A8), be consulted for further information.

3. An example of MRT uncertainty analysis is found in Table H-1. The table provides the results of 3 observers viewing four separate targets. Not shown here are the results of the individual observations made by each observer. An arithmetic mean was used to calculate the average MRT value for each observer. The table shows an average MRTD of 3 observers that was calculated using a geometric mean.

APPENDIX H. DATA ANALYSIS.

**Table H-1. Uncertainty**

| Measured MRTD | | | | |
|---|---|---|---|---|
| **Target** | **Observer 1** | **Observer 2** | **Observer 3** | **Average MRTD of 3 observers (deg C)** |
| 1 | 0.0374 | 0.0610 | 0.0485 | 0.0480 |
| 2 | 0.0488 | 0.0840 | 0.0588 | 0.0622 |
| 3 | 0.0593 | 0.1137 | 0.0799 | 0.0813 |
| 4 | 0.0823 | 0.1406 | 0.1176 | 0.1108 |
| Collimator Transmission | | | 0.98 | |

| Uncertainty Analysis | | | | |
|---|---|---|---|---|
| **Uncertainty Source** | | **Error (deg C) [example]** | **Uncertainty Type** | **SBIR [actual]** |
| 1. Blackbody Delta-T Source Accuracy | | 0.0060 | Bias | 0.0065 |
| 2. Blackbody Temp. Drift (Stability) | | 0.0017 | Precision | 0.0020 |
| 3. Blackbody Uniformity | | 0.0070 | Bias | 0.0065 |
| 4. Observer Standard Error of the Mean (freq.) | | | Precision | |
| | sigma xbar of observers at freq (Target 1) | 0.00086 | | 0.01179 |
| | sigma xbar of observers at freq (Target 2) | 0.0390 | | 0.01816 |
| | sigma xbar of observers at freq (Target 3) | 0.0520 | | 0.02746 |
| | sigma xbar of observers at freq (Target 4) | 0.2400 | | 0.02937 |
| 5. Total Bias Temperature Error (RSS line 1 & 3) in Deg. C | | 0.0092 | | 0.0092 |
| 6. Total Precision Temperature Error (RSS line 2 & 4) | | | | |
| | Precision error (Target 1) | 0.0019 | | 0.0119 |
| | Precision error (Target 2) | 0.0390 | | 0.0182 |
| | Precision error (Target 3) | 0.0520 | | 0.0275 |
| | Precision error (Target 4) | 0.2400 | | 0.0294 |
| 7. Total 2 sigma Temperature Error (Root of Sum of Squares (RSS) of line 5 & 6) | | | | |
| | (Target 1) | 0.0094 | | 0.0151 |
| | (Target 2) | 0.0401 | | 0.0204 |
| | (Target 3) | 0.0528 | | 0.0290 |
| | (Target 4) | 0.2402 | | 0.0308 |
| 8. Percent Ambient Temperature Variation | | 0.7000 | Precision | 0.6667 |
| 9. Percent Collimator Correction Factor | | 2.0000 | Bias | 2.0000 |
| 10. Total Percent Precision Error (RSS) in % | | 0.7000 | | 0.6667 |
| 11. Total Percent Bias Error (RSS) in % | | 2.0000 | | 2.0000 |
| 12. Total Percent Error (RSS of line 10 & 11) | | 2.1190 | | 2.1082 |
| 13. Total MRTD Uncertainty is RSS of Deg C Error (line 7) & (% Error (line 12) * avg. MRTD) | | | | |
| | MRTD Uncertainty (Target 1) [+/-] | 0.1022 | | 0.0151 |
| | MRTD Uncertainty (Target 2) [+/-] | 0.1379 | | 0.0205 |
| | MRTD Uncertainty (Target 3) [+/-] | 0.1803 | | 0.0291 |
| | MRTD Uncertainty (Target 4) [+/-] | 0.3359 | | 0.0309 |

# APPENDIX H. DATA ANALYSIS.

## SOURCES OF ERROR

1. Sources of error are provided in Table H-1 and are described individually below:

Blackbody Delta-T Source Accuracy

2. This value is determined by the specifications of the blackbody and is a measure of the readout accuracy of the blackbody. In this case the accuracy specification for the SBIR blackbody is 0.01 ºC. This value is taken as the accuracy at the entrance aperture of the sensor and, thus, should be corrected for the transmission loss of the collimator. In our case, the transmission of the collimating optics is defined as 98%. So, all readings should be within $0.01 \times 0.98 = 0.0098°C$. This is taken to be the 3 sigma value from which the 2 sigma value is determined. Therefore, the error value defined is $0.0098 \times 2/3 = 0.0065°C$.

Blackbody Temperature Drift (Stability)

3. This value is determined by the specifications of the blackbody and is a measure of the readout stability of the blackbody. In this case the long-term stability specification for the SBIR blackbody is 0.003 C. This value is taken as the blackbody drift at the entrance aperture of the sensor and, thus, should be corrected for the transmission loss of the collimator. In our case, the transmission of the collimating optics is defined as 98%. So, all readings should be within $0.003 \times 0.98 = 0.00294°C$. This is taken to be the 3 sigma value from which the 2 sigma value is determined. Therefore, the error value defined is $0.00294 \times 2/3 = 0.0020°C$.

Blackbody Uniformity

4. This value is determined by the specifications of the blackbody and is a measure of the temperature variability across the surface of the blackbody. In this case the uniformity specification for the SBIR blackbody is unavailable and assigned a value of 0.01 C – equivalent to the worst-case value for temperature accuracy. The worst-case is assumed for this value; that is, the Delta T value is assumed to be incorrect by this amount. It is also assumed to be a bias value, which means it is not reduced by averaging. This value is taken as the uniformity at the entrance aperture of the sensor and thus should be corrected for the transmission loss of the collimator. In our case, the transmission of the collimating optics is defined as 98%. So, all readings should be within $0.01 \times 0.98 = 0.0098°C$. This is taken to be the 3 sigma value from which the 2 sigma value is determined. Therefore, the error value defined is $0.0098 \times 2/3 = 0.0065°C$.

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Observer Standard Error of the Mean

5. This is often the dominant error in the MRTD test. This value will show the extent of observer training as well as characterize the quality of the FLIR. A system with a high observer variability error could indicate either inconsistent criteria used by the set of observers or that the quality of the imagery is poor. Prior history has indicated high correlation between a noisy system and the variability of the observers. As the noise increases, so does the uncertainty in the observer. This value is the standard error of the mean and is calculated as follows:

$$STDEV = \sqrt{\frac{(x-\bar{x})^2}{n-1}}$$

$$\text{Where } \bar{x} = \frac{x_1 + x_2 + x_3 + ... + x_n}{n}$$

6. The observer standard error is calculated for each spatial frequency used during the MRT test, such that the variability is frequency dependent. At each spatial frequency, the final averaged MRTD and the standard deviation is obtained from the averaged response of each observer. In this way, the final averaged MRT value is evenly weighted for all the observers. If one observer performed two MRT runs and another performed three runs, the observer who performed three runs is not weighted more than the observer who only did two.

Total Bias Temperature Error

7. This is determined by calculating the square root of the sum of the squares (RSS) of each of the Bias error values listed under the heading Error (deg C). Errors due to the unrelated sources can be RSSed together to determine the composite error. In this case, line 1 and line 3 are RSSed:

$$\text{(a)}\ \sqrt{0.0065^2 + 0.0065^2} = 0.0092$$

Total Precision Temperture Error

8. The precision errors associated with the hardware, such as temperature quantization and drift are RSSed to the observer variability associated with each target frequency. In this way, a total temperature precision error is obtained for each spatial frequency. In this case, line 2 and each spatial frequency in line 4 is RSSed:

$$\text{(1)}\ \sqrt{0.0020^2 + .01179^2} = 0.0119, \sqrt{0.0020^2 + 0.01816^2} = 0.0182$$

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Total 2-sigma Temperature Error

9. This is determined by the RSS of the bias errors in line 5 with each of the precision errors in line 6.

$$(1)\ \sqrt{0.0092^2 + .0119^2} = 0.0151, \sqrt{0.0092^2 + 0.0182^2} = 0.0204$$

Percent Ambient Temperature Variation

10. An error which occurs when the change in photon flux due to ambient temperature differences are not accounted for. Most blackbodies report the difference in temperatures between the source and background but do not make provisions to adjust for the chance in photon flux at different background temperatures. Analysis indicates that the equivalent temperature difference can vary by +/- 1% as the ambient temperature varies +/- 1 degree C which is the spec value for most room's temperature control accuracy. Therefore, 1 degree C is taken to be a 3 sigma value from which the 2 sigma uncertainty is calculated. Therefore, the error value defined is $0.01 \times {}^2\!/_3 \times T_c = 0.0065°C$. For tests where the ambient conditions cannot be controlled (i.e., hangar environment), this value may be much larger. In fact, by allowing the ambient temperature to drift from 25 to 32C (77 to 89.6F) a 1 deg delta T results in an apparent delta T of 1.22164 (MWIR) or 1.07101 (LWIR). This is an approximate error of 22% and 7% respectively. *Note: This is dependant on the waveband of interest. It may be possible to control this error if a radiometric delta T capability (available with the ACTS) is used.*

Percent Collimator Correction Factor

11. This compensates for the transmission losses of the optics of the test set. This factor accounts for the instrument errors in measuring power transmission. It also accounts for the error resulting from using a single number to characterize the entire spectral band of the sensor. Collimator transmission loss is generally reported as a percent of the actual blackbody temperature. The estimate is for 2 sigma to be 2%.

Total Percent Precision Error

12. The Precision elements in the table which have been reported as percents are RSSed. In this example, the only bias error reported is the Ambient Temperature Variation (line 8).

Total Percent Bias Error

13. The Bias elements in the table which have been reported as percents are RSSed. In this example, the only bias error reported is the Collimator Correction Factor (line 9).

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Total Percent Error

14. All elements reported as percentages are RSSed. In this example, the errors on line 10 and line 11 are RSSed to determine total percent error:

(a) $\sqrt{0.6667^2 + 2.0^2} = 2.1082$

Total MRTD Uncertainty

15. The uncertainties have been expressed so far as two types, either temperatures (line 7) or percentages of the called MRT (line 12). These two must next be combined to obtain the final uncertainty at each spatial frequency. The total percentage value (line 12) is multiplied by the average MRT for each spatial frequency. This result is then RSSed by the total temperature error (line 7) to produce the final uncertainty value at that spatial frequency. This is usually reported as an error bar around the average MRT at each spatial frequency (see Figure H-1)

(1) MRTD Uncertainty Target 1 = $\sqrt{\left(\frac{2.1082}{100} \times 0.0480\right)^2 + 0.0151^2} = 0.0151$,

(2) MRTD Uncertainty Target 2 = $\sqrt{\left(\frac{2.1082}{100} \times 0.0622\right)^2 + 0.0204^2} = 0.0205$,

(3) MRTD Uncertainty Target 3 = $\sqrt{\left(\frac{2.1082}{100} \times 0.0813\right)^2 + 0.0290^2} = 0.0291$,

(4) MRTD Uncertainty Target 4 = $\sqrt{\left(\frac{2.1082}{100} \times 0.1108\right)^2 + 0.0308^2} = 0.0309$

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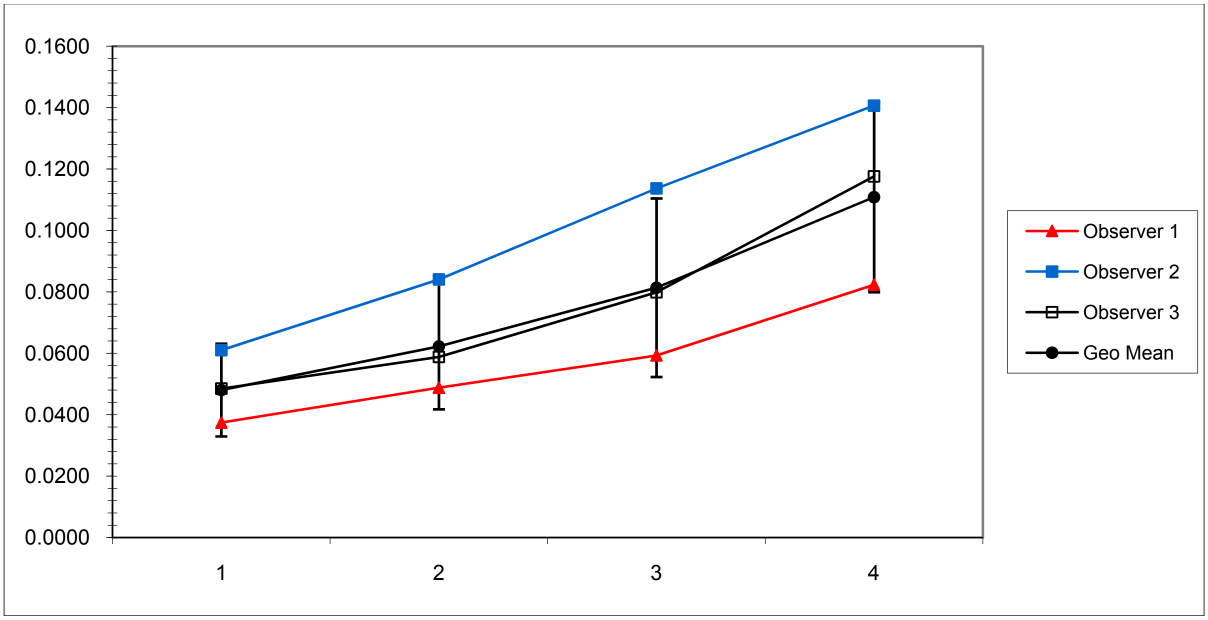


**Figure H-1. MRT and Uncertainties**

INTERPRETING DATA

In general, an analyst will be interested in determining whether the system passes specifications. After that, the majority of analysis is based on trends observed in the data collected. The following are some areas to be aware of when analyzing data.

Test Subject Variability

1. The dominant error for MRTD testing is often test subject variability. As stated previously in the section regarding observer error, a noisy system can contribute to large variabilities between observers. However, most systems these days (i.e., 2nd gen and 3rd gen sensors) typically have very low noise. Therefore, one of the most likely candidates for noticeable observer variability becomes the observer themself. MRTD testing is very subjective and it is common for individuals to interpret MRTD differently. Ideally, test participants have been trained to identify MRTD by someone who is recognized and established as an MRTD test subject. This often entails someone who has performed numerous MRTD tests, someone with a low detection threshold, someone who has a low variability within their test results, and someone whose results have consistently identified functioning or non-functioning systems. Holst (ref A2) provides additional insight into observer qualifications in Chapter 10 of his book. Because of the subjective nature of this test, a well defined MRTD test will consist of multiple observations with multiple observers. One benefit of this approach allows the analyst to determine trends of the individual observer

APPENDIX H. DATA ANALYSIS.

and trends across multiple observers. During testing, review data from at least two runs and ensure the trends of the data are at least consistent. There may be a bias offset that affects the whole data set, but there should be no extreme outliars without justification. If outliars are observed, it would be prudent to take a third data set. Figure H-2 shows an example data set for two MRT observations (assume the same test subject). As you can see, MRT data has a general exponential trend. The standard method of plotting MRTD data is with the vertical axis in a logarithmic scale as shown in Figure H-3. This generally makes observation of the data easier and highlights any changes. Both data sets are identical except for the y-scale used for plotting.

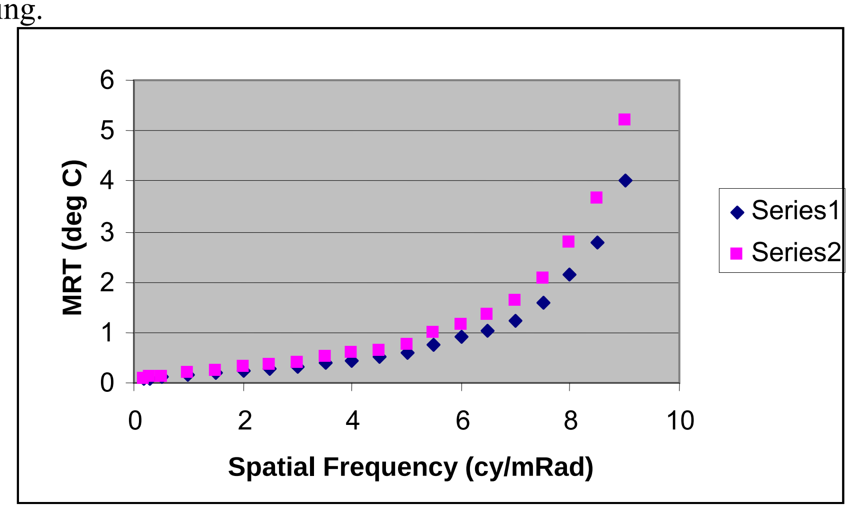


**Figure H-2. Example MRT Data**

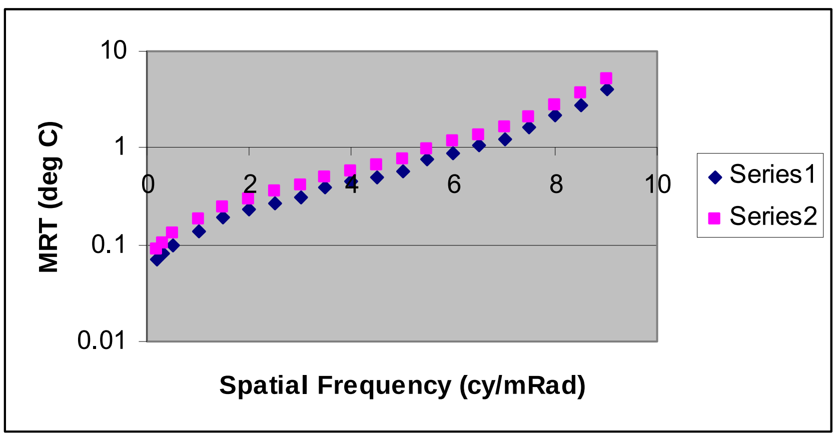


**Figure H-3. MRT Example (Log Scale)**

2. As you can see clearly in Figure H-3, the trends from both sets of MRTD data are identical. The only difference appears to be an offset. This shows great consistency between runs and implies the test subject uses a well defined set of criteria for calling the MRTD point. Therefore, the offset observed in Figure H-3 would likely be attributed to something other than test subject abilities.

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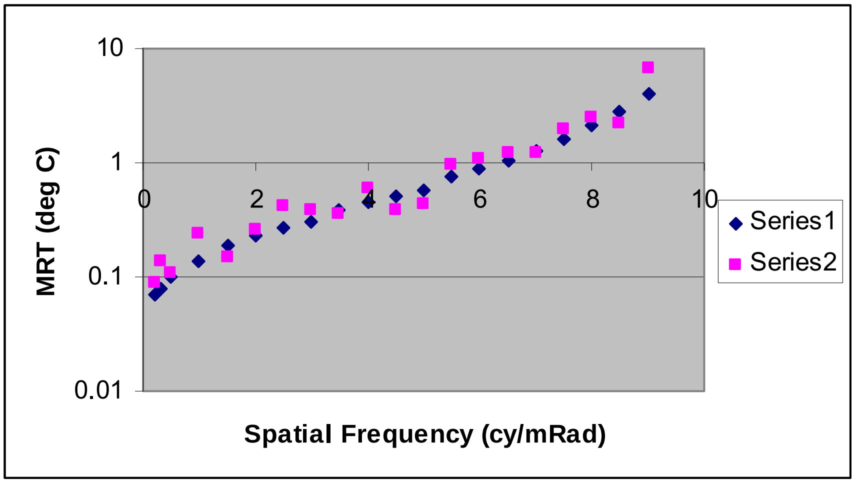


**Figure H-4. Inconsistent MRT Results**

3. Figure H-4 shows a similar test condition; however, notice the inconsistency of the results. The test subject may not have a consistent threshold definition for an MRTD. Anything outside the general exponential trend should be evaluated closely to identify a cause. On this logarithmic scale, it would be expected that, in general, data would trend linearly upward. Data points where the values go down considerably would be suspect and may be considered outliers. While it is not uncommon to see some random bouncing in data, the desire is to narrow the gap from run to run. This process is a learned ability that often requires practice and feedback on results.

Environmental Variability

4. When data is consistent but has a general bias or offset, as the trend shows in Figure H-3, there are a few possible culprits. First, consider ambient temperature drift. Data sets taken at different times of the day or over multiple days could be affected by a change in ambient temperature. As shown in Appendix B: Apparent Temperature, a temperature drift of 1 ºC can cause a corresponding drift in deltaT values of 0.1 ºC. Ideally, MRTD testing is performed in a laboratory where ambient temperature does not drift. If this is not possible, test notes should describe the conditions and ambient temperature changes should be recorded.

5. Another culprit could be attributed to sensor focus changes. The sensor should be optimized for focus at the beginning of each test. Variations in the focus level could affect the test subject's ability to resolve a 4-bar target. The result is the test subject increases the temperature difference until it is resolvable, resulting in an increased MRTD level.

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Horizontal MRTD and Vertical MRTD

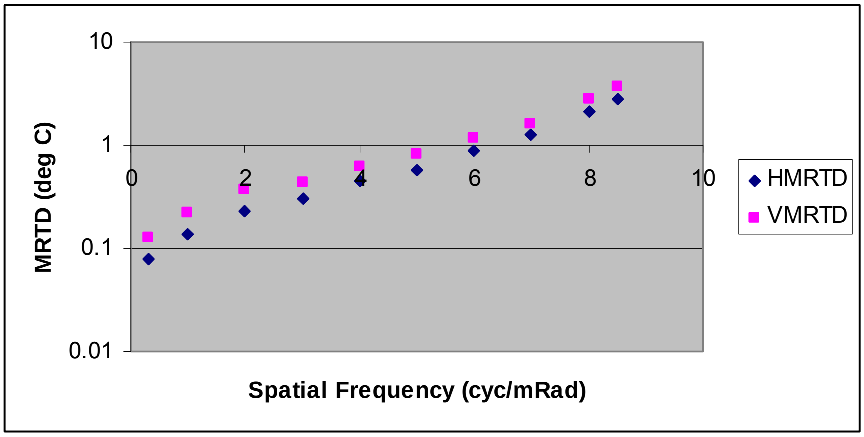


**Figure H-5. Horizontal and Vertical MRTD**

6. Figure H-5 shows a characteristic set of Horizontal and Vertical MRTD curves for a parallel scanned imager. VMRTD curves typically have values greater than the HMRTD curves. The exception is for a staring array where the detectors and sampling grid are square. In this case it is possible to have VMRTD and HMRTD values be identical. In general, the MRTD values for horizontal and vertical targets are dependent on detector resolution or sampling factors. Parallel scanned imaging systems typically obtain more samples in the scanned direction and therefore can detect higher spatial frequency targets. Staring systems with identical vertical and horizontal resolutions will not have a bias for either orientation based on resolution. Variations of vertical and horizontal MRTDs described are not the rule but are for consideration. It is possible that vendors may perform digitial processing that affects HMRTD and VMRTD results but understanding the test unit will help identify any variations.

Aliasing

7. Normal system use, where input scenes contain complex target and background imagery, does not typically reveal aliasing and most test subjects may not understand the results or appearance of aliasing. Although aliasing affects all sampled systems, it is most apparent and understandable when discussing periodic input imagery (e.g., spatial frequency of a square wave signal from 4-bar targets). Sampling theory says a signal can be recovered for all input frequencies below Nyquist frequency. For any frequency above the Nyquist frequency of a sampled system, the input signal will be aliased down to a lower frequency. This means that any 4-bar target with a spatial frequency that exceeds the Nyquist frequency of the sensor will appear to the test subject as a target of lower spatial frequency. Appendix B, System Cutoff, describes how to calculate the cutoff frequency (nyquist frequency) of a system if it is not provided by the manufacturer. The following diagrams show examples of

APPENDIX H. DATA ANALYSIS.

a series of detectors viewing a 4-bar target and the resulting output signal. Figure H-6 shows a system where the target frequency ($f_0$) is ½ the detector sampling frequency, defined as the Nyquist frequency ($f_N$). In other words there are 2 detectors for every full target cycle. The alignment of the detectors and the input target is such that the output signal is defined as "in phase." All input energy is summed in a single detector from a single bar. Figure H-7 shows the same target and detector with an "out of phase" alignment of the target. Notice that each detector only collects a portion of the input signal. The effect is a reduction of the signal contrast. A test subject could possibly identify 4-bars, but would likely require an increase in target temperature to resolve. Figure H-8 shows a target with a frequency $f_0 > f_N$. A test subject would not easily resolve this target because 4-bars can not be distinguished properly. In fact, tests described by Holst as performed by Webb (page 348) show that test subjects may detect targets, however they are actually detecting aliased signals from the target that appear as 4-bar targets of a lower spatial frequency (signal is aliased down).

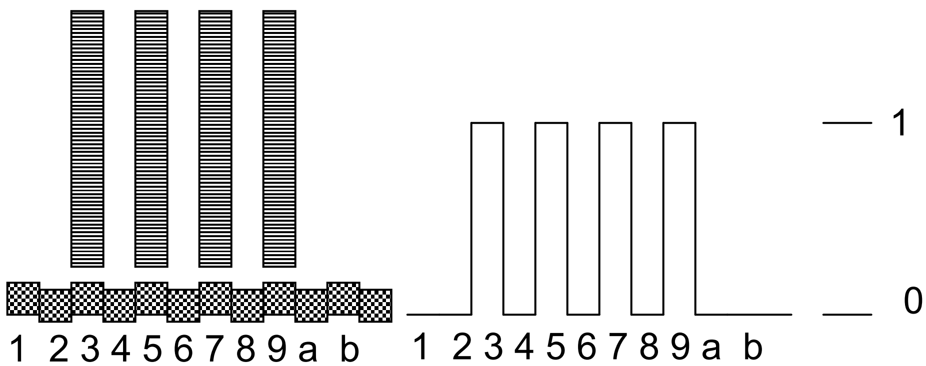


**Figure H-6. Sampling Example (In-Phase, Nyquist Frequency Target)**

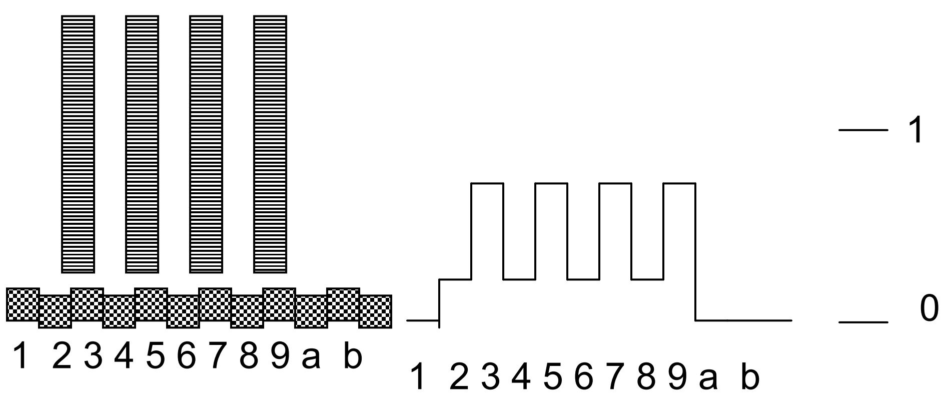


**Figure H-7. Sampling Example (Out-of-Phase, Nyquist Frequency Target)**

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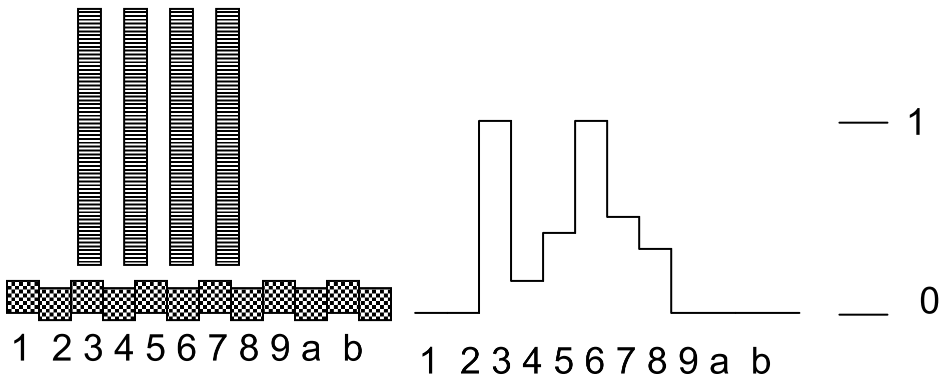


**Figure H-8. Sampling Example (Target Frequency > Nyquist)**

8. For most systems, testing beyond Nyquist frequencies is not recommended due to this issue of aliasing. Figure H-9 out of Holst, page 348, shows that, in fact, certain spatial frequencies ($f_0/f_N$ between 0.6 and 0.9) are not easily resolvable due to aliasing and phasing issues. Holst comments about the importance of realizing that it is not correct to simply draw a line between data points when interpolating data. This graph shows that certain features may be missed. While the ideal situation would be to pick targets that avoid aliasing or phasing issues, it is not always possible due to cost or availability of targets.

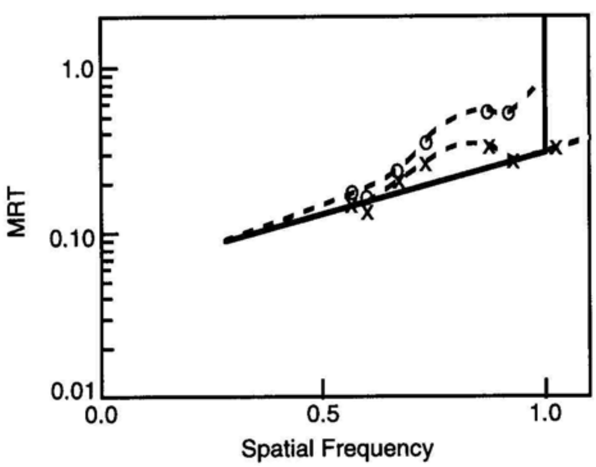


**Figure H-9. Aliasing Effects**

Contrast Threshold Response

9. It is discussed by Holst, page 336, that the MRTD data will generally follow the shape of the eye's threshold curve (Figure H-10). He explains that the eye resembles an AC coupled system and has more difficulty resolving large targets (low spatial frequencies). This will cause the MRTD data to increase at the low frequency end. Resolving low frequency targets is also strongly affected by the distance from the monitor or head motion (Figure H-11). These figures show that as the test subject is free to move, resolving the targets becomes easier and the MRTD data values decrease at the low frequency range. The distance from the monitor or the requirement to remain stationary is often not dictated in the test plans;

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however, the data analysts should be made aware of how the data was collected. Unless the normal operation of the test device specifies otherwise, data will be most consistent by dictating a known observation distance and by minimizing test subject motion during data collection.

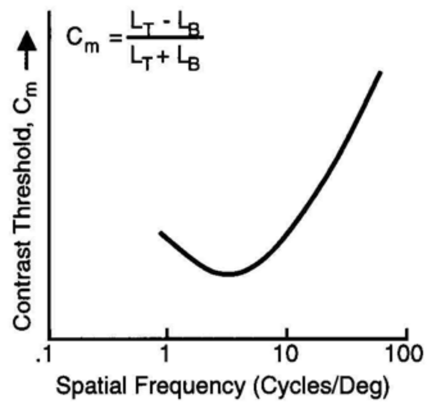


**Figure H-10. Eye Threshold Curve**

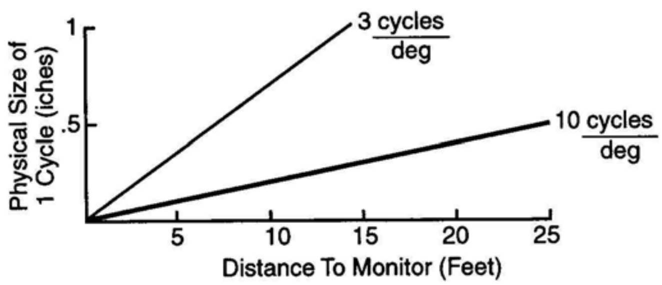


**Figure H-11. Optimal Viewing Distance**

Noise Effects on Contrast Response

10. As mentioned previously, the MRTD data curves are affected by the eye's contrast threshold. The standard contrast threshold model is represented by a J-like curve [as seen in Figure H-12] and Holst, page 340,. One benefit of new generation FLIR sensors is their use of digital processing to minimize the affects of noise on the image. In older analog systems, it was common to see a combination of noise that ranged from low-frequency, fixed pattern noise (bands in the image) to high frequency salt-and-pepper type noise. Often the manufacturers of newer systems using digital processing will make trade trade-offs regarding

APPENDIX H. DATA ANALYSIS.

the level of noise elements. Performing MRTD doesn't provide the best method of determining the noise components present in an image. At best it may be possible to determine some trends in the data. Figure H-12 shows how types of noise can affect the contrast threshold curve (or MRTD curves). Banding and non-uniformity can be attributed to low-frequency type noise and will raise the detection threshold on low-frequency targets. These factors will tend to annoy or distract the test subject while trying to view targets. High frequency such as fixed pattern noise or salt-and-pepper noise will affect a test subject's ability to resolve high spatial frequency targets. The high frequency noise makes resolving details difficult and will interfere with basic operations. Random white noise tends to raise the contrast across the entire spectrum. Holst provides example imagery of some types of noise in a chapter on "System Noise." This reference also describes an alternate test, called 3D-Noise, that is, useful for determining the noise components in a system.

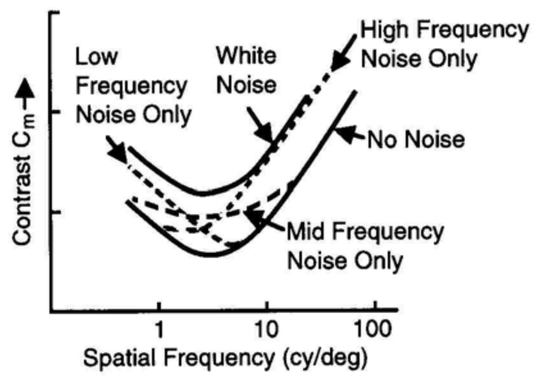


**Figure H-12. Effects of Spectral Noise on Contrast Threshold**

APPENDIX I. PRESENTATION OF DATA.

The material in this appendix provides guidelines to produce clear, consistent tables and plots of MRTD data used for presentations and technical reports.

DATA TABLES

General

1. The examples below respresent methods to organize MRTD test data. They are based on example spreadsheets developed to process the data.

Individual Data Sheet

2. The individual data sheet (Table I-1) represents a tool for use during testing by the test subject. It provides a convenient record of the test event, test equipment, sensor under test, environmental conditions and test data. Not all tests will require both Vertical and Horizontal MRTD data and some tests may require additional test targets. This provides a template to design specific test data sheets. Data from these test sheets are used to analyze MRTD results and typically the detailed data points are not reproduced in the final test report.

Table I-1. Individual Data Sheet

| [SYSTEM NAME HERE] System Level MRT Testing | | |
|---|---|---|
| **General Test Info** | | |
| Date: **[DAY] [MONTH] [YEAR]** | Location: | Test Event Times: Start- End- |
| **Aircraft Info** | | |
| Aircraft Tail #: **[VALUE HERE]** | DP Version #: | SP Version #: |
| WP Version #: | [DISPLAY] Version #: | HMD Version #: |
| [SYSTEM NAME] SW Version #: | [SYSTEM NAME] System #: | |
| **Test Event Info** | | |
| Observer Name: **[NAME HERE]** | Collimator: ATTC SBIR SN#: **3085** | |
| Sensor Under Test: **[SENSOR NAME]** | Sensor FOV: **NARROW** | Display Device: **[DISPLAY TYPE]** |
| Aircraft Power Source: **HANGER GND** | Aircraft ECU: On Off | |
| Ambient Temp: | Rel Humidity: | Wind Speed/Direction: |
| Cockpit Station: **CPG** | Cockpit Condition: **Blackout** | |
| Additional Comments on Test Set Up: | | |

| Bar Tgt Orient[1] | T# / Freq (cy/mr) | Bar Tgt Contrast[2] | dT (ºC) | T1 (ºC) | RdT (ºC) | | Bar Tgt Orient[1] | T# / Freq (cy/mr) | Bar Tgt Contrast[2] | dT (ºC) | T1 (ºC) | RdT (ºC) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VERTICAL | **7 / 6.5** | Hot | 0.103 | 24.896 | 0.103 | | HORIZONTAL | **7 / 6.5** | Hot | 0.253 | 25.019 | 0.253 |
| | | Cold | -0.122 | 24.826 | -0.122 | | | | Cold | -0.222 | 24.949 | -0.222 |
| | **8 / 9.5** | Hot | 0.305 | 24.731 | 0.305 | | | **8 / 9.5** | Hot | 0.455 | 24.854 | 0.455 |
| | | Cold | -0.266 | 24.617 | -0.266 | | | | Cold | -0.366 | 24.74 | -0.366 |
| | **9 / 11.5** | Hot | 0.49 | 24.526 | 0.49 | | | **9 / 11.5** | Hot | 0.64 | 24.649 | 0.64 |
| | | Cold | -0.487 | 24.419 | -0.487 | | | | Cold | -0.587 | 24.542 | -0.587 |
| | **NA** | Hot | | | | | | **NA** | Hot | | | |
| | | Cold | | | | | | | Cold | | | |
| | **NA** | Hot | | | | | | **NA** | Hot | | | |
| | | Cold | | | | | | | Cold | | | |

Additional Test Execution Comments:

1) Vert. Bar Orientation Correlates to Horizontal Sensor MRT Performance & Vice Versa
2) WRT Ambient Target Wheel Background Temp (T1)

Data Collector Signature

APPENDIX I. PRESENTATION OF DATA.

Combined Observer Data Table

3. The following table (Table I-2) summarizes the data collected from all the observers. There may be two of these tables that define the results for the Vertical and Horizontal MRTD. Each of the individual observer runs should represent their combined data set results. The average value shown here is the combination of the separate observer's results and defines the accepted MRTD value for the given target. This data table should be included in the test report along with the data plots.

Table I-2. Combined Observer Data

| Measured MRTD | | | | |
|---|---|---|---|---|
| **Target** | **Observer 1** | **Observer 2** | **Observer 3** | **Average** |
| **6.5** | 0.089 | 0.137 | 0.103 | 0.108 |
| **9.5** | 0.217 | 0.249 | 0.325 | 0.260 |
| **11.5** | 0.418 | 0.356 | 0.606 | 0.503 |

Error Analysis Tables

4. The error analysis table (Table I-3) defines the critical elements of uncertainty in performing the MRTD test. The details of this table were described in the Appendix H. The uncertainty results for each of the individual targets, labeled "MRTD Uncertainty (Target 1) [+/-]" and shown at the bottom of the table, are the values used to draw error bars on the data plots. The entire table may be used in the test report to present the reader with background on the primary error sources of the test.

APPENDIX I. PRESENTATION OF DATA.

**Table I-3. MRTD Uncertainty Calculations**

| | | | |
|---|---|---|---|
| Collimator Transmission | 0.98 | | |
| **Uncertainty Analysis** | | | |
| **Uncertainty Source** | | **Type** | **SBIR** |
| 1. Blackbody Delta-T Source Accuracy | | Bias | 0.0065 |
| 2. Blackbody Temp. Drift (Stability) | | Precision | 0.0020 |
| 3. Blackbody Uniformity | | Bias | 0.0065 |
| 4. Observer Standard Error of the Mean (freq.) | | Precision | |
| | sigma xbar of observers at freq (Target 1) | | 0.02477 |
| | sigma xbar of observers at freq (Target 2) | | 0.05544 |
| | sigma xbar of observers at freq (Target 3) | | 0.13054 |
| 5. Total Bias Temperature Error (RSS line 1 & 3) in Deg. C | | | 0.0092 |
| 6. Total Precision Temperature Error (RSS line 2 & 4) | | | |
| | Precision error (Target 1) | | 0.0248 |
| | Precision error (Target 2) | | 0.0555 |
| | Precision error (Target 3) | | 0.1306 |
| 7. Total 2 sigma Temperature Error (RSS of line 5 & 6) | | | |
| | (Target 1) | | 0.0265 |
| | (Target 2) | | 0.0562 |
| | (Target 3) | | 0.1309 |
| 8. Percent Ambient Temperature Variation | | Precision | 1.2590 |
| 9. Percent Collimator Correction Factor | | Bias | 2.0000 |
| 10. Total Percent Precision Error (RSS) in % | | | 1.2590 |
| 11. Total Percent Bias Error (RSS) in % | | | 2.0000 |
| 12. Total Percent Error (RSS of line 10 & 11) | | | 2.3633 |
| 13. Total MRTD Uncertainty is RSS of Deg C Error (line 7) & (% Error (line 12) * avg. MRTD) | | | |
| | MRTD Uncertainty (Target 1) [+/-] | | 0.0266 |
| | MRTD Uncertainty (Target 2) [+/-] | | 0.0566 |
| | MRTD Uncertainty (Target 3) [+/-] | | 0.1314 |

PLOTS

General

1. The plots below represent graphical descriptions of the MRTD data. These examples are acceptable methods for presenting data in technical reports.

Horizontal/Vertical MRTD Plots

2. It may be necessary to document a specific individual’s results in the report to highlight an issue. Figure I-1 demonstrates a simple plot of the observer’s Vertical and Horizontal MRTD. Notice the Y-axis is ploted on a logarithmic scale because this is the standard method for plotting MRTD data.

APPENDIX I. PRESENTATION OF DATA.

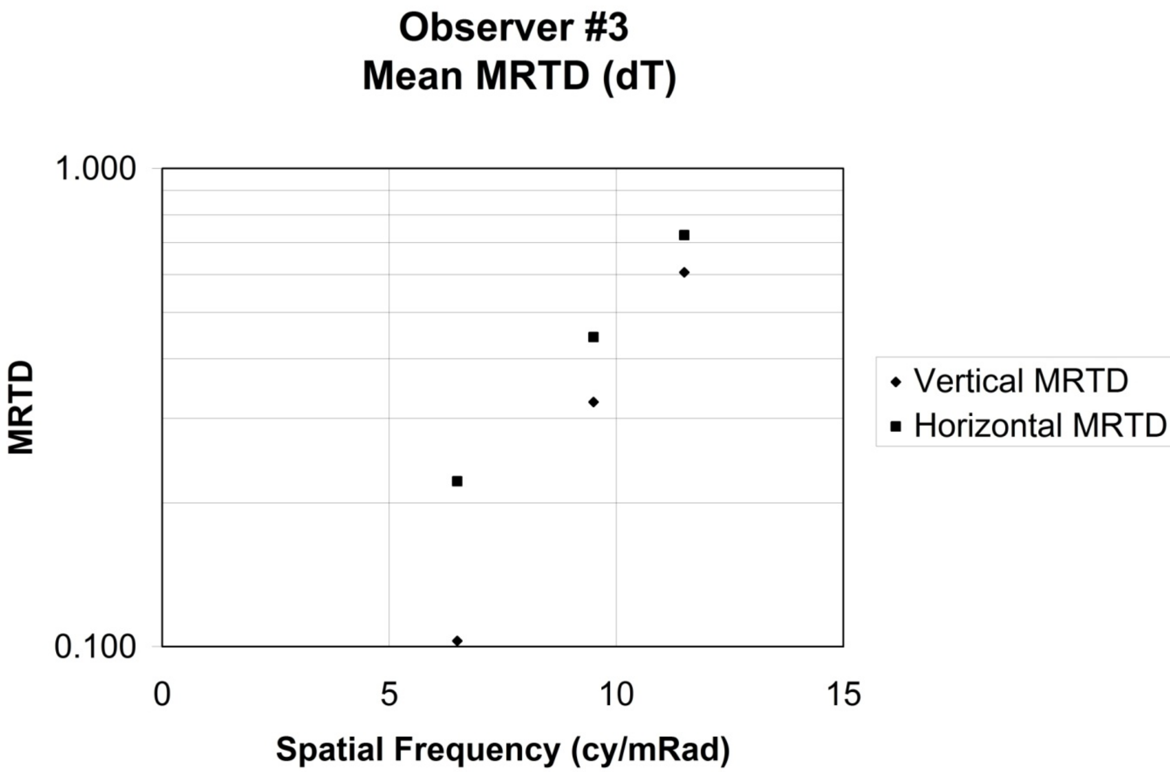


**Figure I-1. Horizontal/Vertical MRTD Plot**

3. Figure I-2 is a useful graph to present the variation between observers. This figure plots the average MRTD value for each observer. Ideally, these groupings will be tight between observers and any outliars will highlight possible issues with the test conditions.

APPENDIX I. PRESENTATION OF DATA.

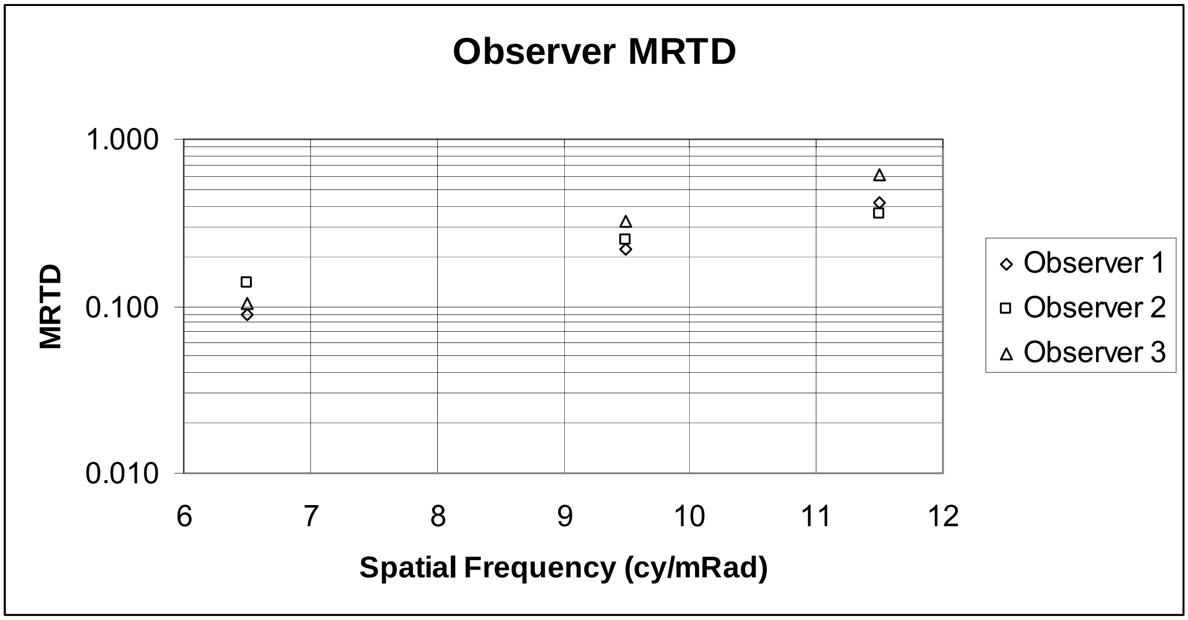


**Figure I-2. Observers Average MRTD**

<u>Uncertainty Analysis Plots</u>

4. Figure I-3 combines the results of all the observers into a single MRTD value. Error bars are defined based on the uncertainty analysis. Then, the MRTD specification values for the sensor under test are drawn to determine graphically if the unit has passed or failed. Notice, it isn't always possible to select target values with the exact spatial frequency of the specification. The general trends should be within the specification tolerance. Ideally, the targets selected will bound the MRTD specification.

APPENDIX I. PRESENTATION OF DATA.

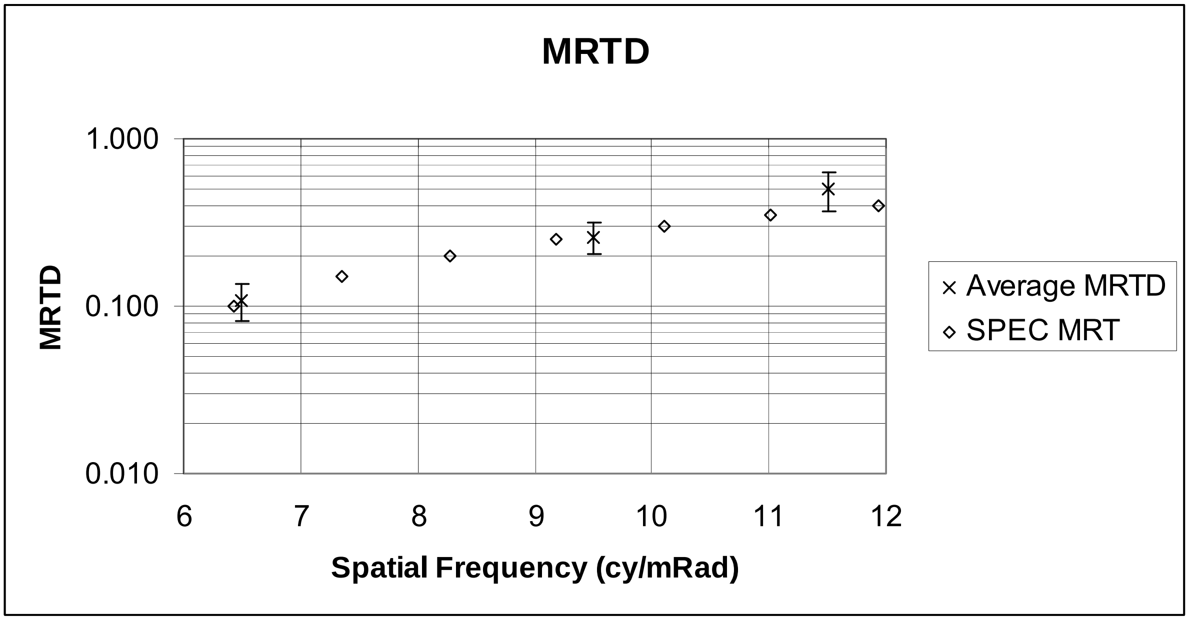


**Figure I-3. MRTD with Uncertainty and SPEC Values**

# APPENDIX J. REFERENCES.

1. International Test Operations Procedures, FR/US/UK ITOP 6-3-040 Thermal Imaging Systems, 14 November 2000.

2. Holst, Gerald C., *Testing and Evaluation of Infrared Imaging Systems*, JCD Publishing Company, Maitland, FL, 1993.

3. Driggers, R., (et al.), "Equivalent Temperature Differences with Respect to Ambient Temperature Differences as a Function of Background Temperature," *Optical Engineering*, Vol. 31, No. 6, June 1992.

4. Driggers, R., (et al.), "Laboratory Measurement of Sampled Infrared Imaging System Performance," *Optical Engineering*, May 1999.

5. Wolfe, W., (et al.), *The Infrared Handbook*, Office of Naval Research, 1978.

6. STANAG 4349, 1st Edition, *Measurement of the Minimum Resolvable Temperature Difference (MRTD) of Thermal Cameras*, 1995.

7. STANAG 4161, 1st Edition, *The Optical Transfer Function of Imaging Systems*, November 1982 and Amendment 1, dated February 1984.

8. Biberman, Lucien M., (et al.), *Electro-Optical Imaging: System Performance and Modeling*, SPIE Press, Bellingham, WA, January 2001.

9. Johnson, J., "Analysis of Image Forming Systems," *Proceedings Image Intensifier Symposium*, U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, 6-7 October 1958 (AD220160).

10. Memorandum, U.S. Army Aviation Technical Test Center (ATTC) Memo 70-12, February 1998, with Change 2, 30 June 1998, subject: Research, Development, and Acquisition, Aviation Test Director's Handbook.

11. U.S. Naval Test Pilot School Flight Test Manual (USNTPS-FTM) No. 109, *Systems Testing*, Naval Air Warfare Center, January 1998.

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: US Army Redstone Test Center (TEDT-AC-FT-I), Cairns Army Airfield, Ft. Rucker, AL 36362-5276. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.